Appalachian State University
BOONE, NORTH CAROLINA

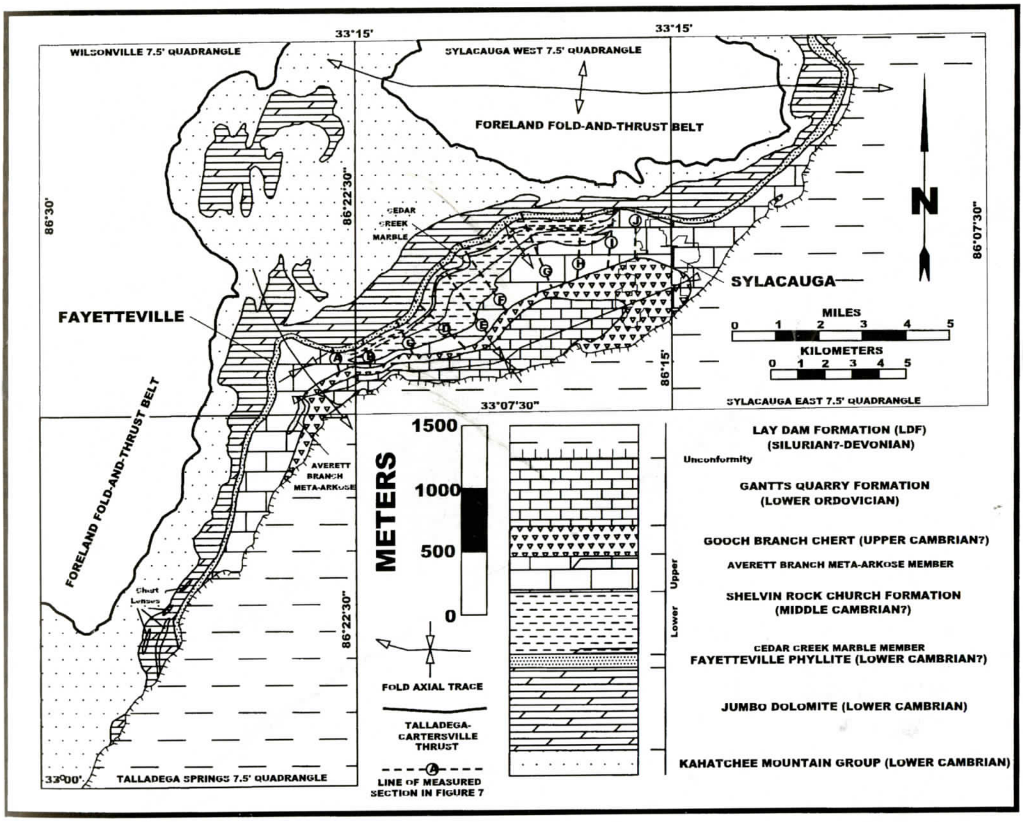
Southeastern Geology: Volume 41, No. 2
July 2002

Editor in Chief: S. Duncan Heron, Jr.

Abstract

Academic journal published quarterly by the Department of Geology, Duke University.

SOUTHEASTERN GEOLOGY



VOL. 41, NO. 2 JULY 2002

SOUTHEASTERN GEOLOGY
Duke University
Box 90233
Durham, NC 27708-0233

Returned Service Requested

Non-Profit Org.
U. S. POSTAGE
P A I D
Durham, NC
Permit No. 60

BELK LIBRARY
SERIALS DEPT
APPALACHIAN STATE UNIVERSITY
PO BOX 32026
BOONE NC 28608

SOUTHEASTERN GEOLOGY

Table of Contents

Volume 41, No. 2 July 2002

SOUTHEASTERN GEOLOGY

PUBLISHED

at

DUKE UNIVERSITY

Editor in Chief:

Duncan Heron

This journal publishes the results of original research on all phases of geology, geophysics, geochemistry and environmental geology as related to the Southeast. Send manuscripts to **DUNCAN HERON, DUKE UNIVERSITY, DIVISION OF EARTH & OCEAN SCIENCES, BOX 90233, DURHAM, NORTH CAROLINA 27708-0233**. Phone: 919-684-5321, Fax: 919-684-5833, Email: duncan.heron@duke.edu Please observe the following:

1) Type the manuscript with double space lines and submit in duplicate.
2) Cite references and prepare bibliographic lists in accordance with the method found within the pages of this journal.
3) Submit line drawings and complex tables reduced to final publication size (no bigger than 8 x 5 3/8 inches).
4) Make certain that all photographs are sharp, clear, and of good contrast.
5) Stratigraphic terminology should abide by the North American Stratigraphic Code (American Association Petroleum Geologists Bulletin, v. 67, p. 841-875)

Subscriptions to *Southeastern Geology* for volume 41 are: individuals - $22.00 (paid by personal check); corporations and libraries - $28.00; foreign $34. Inquires should be sent to: **SOUTHEASTERN GEOLOGY, DUKE UNIVERSITY, DIVISION OF EARTH & OCEAN SCIENCES, BOX 90233, DURHAM, NORTH CAROLINA 27708-0233**. Make checks payable to: *Southeastern Geology.*

Information about SOUTHEASTERN GEOLOGY is on the World Wide Web including a searchable author-title index 1958-2001 (Acrobat format). The URL for the Web site is:

http://www.southeasterngeology.org

SOUTHEASTERN GEOLOGY is a peer review journal.

ISSN 0038-3678

SOUTHEASTERN GEOLOGY
V. 41, No. 2, July 2002, p. 75-102

Sylacauga Marble Group: Distal Fragment of the Southern Appalachian Cambrian-Ordovician Carbonate Platform

Lance W. Johnson[1] and James F. Tull

Department of Geological Sciences, Florida State University, Tallahassee, FL 32306

1. Current Address: Schlumberger Oil & Gas Information Solutions, 5599 San Felipe, Suite 1700, Houston, TX 77056

ABSTRACT

The most complete outboard fragment of the Lower Cambrian-Lower Ordovician Laurentian carbonate platform sequence in the southern Appalachian orogen is the Sylacauga Marble Group. This group is located at the extreme southwest flank of the exposed orogen in Alabama within the Talladega belt, a lower greenschist facies allochthon that is a southwestern continuation of the western Blue Ridge thrust sheet. Important similarities in age, lithofacies, thickness, and lithologic sequence with the Lower Cambrian-Lower Ordovician carbonate platform sequence in the Appalachian foreland confirm close correlation of the Sylacauga Marble Group with the more inboard parts of the Laurentian margin shelf. Preservation of primary features and fossils document that the >2 km thick marble sequence formed predominantly in intertidal to shallow-marine settings that persisted for ~ 80 m.y. Palinspastic restoration places deposition of the marble sequence along the Alabama structural recess, formerly the southernmost continental promontory (oceanward projection) of southeast Laurentia, in a distal position very near the outer margin of that continent. This suggests the presence of a broad carbonate platform several hundred kilometers wide, with a generally consistent platform architecture and depositional setting extending from more inboard foreland regions to near the shelf edge. The Alabama promontory evolved as an upper plate (proximal) rifted margin, and as such experienced minimal lithospheric thinning and development of only a narrow continental shelf. The near-shelf edge position of the Talladega belt along an upper plate (distal) rifted margin apparently enabled peritidal growth of the early Paleozoic carbonate platform to extend nearly to the outer edge of continental crust.

INTRODUCTION

The most completely preserved distal fragment of the Laurentian early Paleozoic trailing continental margin in the southern Appalachian orogen is within the Talladega belt, along the Alabama structural recess (Figure 1). The highly allochthonous Talladega belt, a southwestern continuation of the western Blue Ridge thrust sheet, extends northeastward from the Cretaceous unconformity of the Gulf Coastal Plain onlap in Alabama to Cartersville, Georgia (Figure 1). It contains metamorphosed (lower greenschist facies) equivalents of the Lower Cambrian-Lower Ordovician Laurentian carbonate platform sequence represented by the Sylacauga Marble Group. The western Blue Ridge/Talladega belt initially formed along the southeastern margin of Laurentia during latest Proterozoic rifting and subsequent early Paleozoic drifting associated with the initiation and opening of the Iapetus Ocean (Rankin and others, 1989). Palinspastic restoration indicates that this Alleghanian (late Paleozoic) thrust sheet was originally located very near the Laurentian continental shelf edge (Iapetus western margin), at least as far southeast as the present location of the Pine Mountain internal basement massif (Thomas and others, 2000) (Figure 1). The Alleghanian suture between Laurentia and outboard (African?) terranes is only ~50 km farther southeast of the Pine Mountain massif (Hatcher, 1989). During the Cambrian, southern Laurentia straddled the equator and portions of it existed between 20° and 30° south latitude

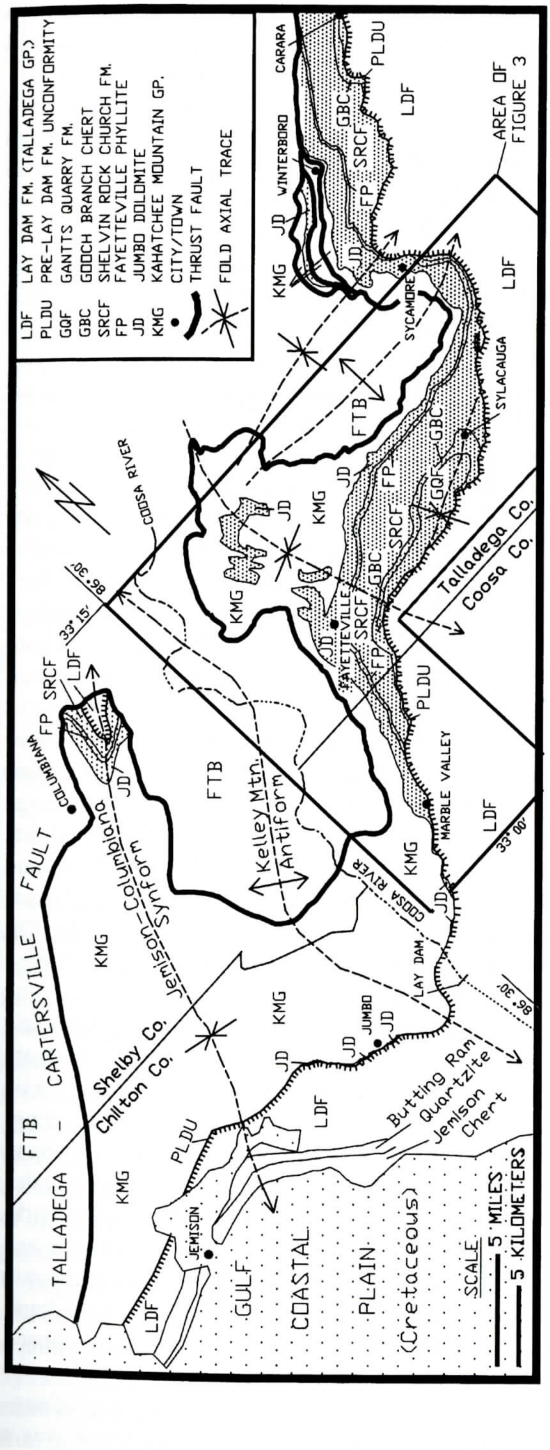


Figure 2. Generalized geologic map of the southwestern Talladega belt showing the location of the Sylacauga Marble Group (fine stipple) and Figure 3. FTB-foreland fold and thrust belt.

results, in combination with detailed mapping of the marble sequence, provide the foundation for correlation of the Sylacauga Marble Group with the Cambrian-Ordovician carbonate sequence in the Appalachian foreland.

GEOLOGIC SETTING

The Talladega belt is bounded below by the Talladega-Cartersville fault, a segment of the Alleghanian-age frontal Blue Ridge thrust system (Figures 1 and 2). This fault separates the unmetamorphosed to weakly metamorphosed lower to upper Paleozoic rocks of the foreland fold-and-thrust belt on the northwest from the lower greenschist facies Talladega belt (Figures 1 and 2). Field mapping indicates a minimal horizontal net slip on this fault relative to the immediate (also highly allochthonous) footwall of 23 km, and a stratigraphic throw of 5 to 7 km. Palinspastic restoration based upon strike-perpendicular balanced cross sections indicates a total translation of the Talladega belt of >100 km (Thomas and others, 2000). Thus, the Talladega belt is highly allochthonous, having overridden by a great distance equivalent and younger-age rocks in the Appalachian foreland. The frontal fault is regionally discordant to units in both hanging walls and footwalls. The lower half of the Talladega belt consists of two metasedimentary sequences overlain by a regional unconformity (Figure 2). The lowermost sequence is a thick (>2 km) siliciclastic unit, the Kahatchee Mountain Group, which is the southeastern equivalent of the Lower Cambrian Chilhowee Group (Tull, 1982). This group is believed to have formed during initial continental drifting and estab-

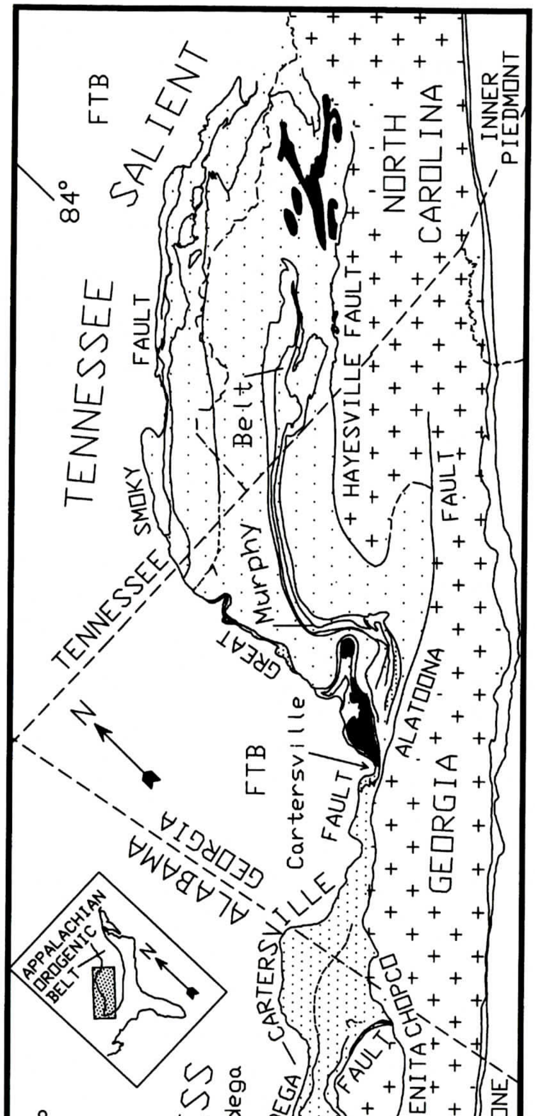


Figure 1. Generalized geologic map of the southern Appalachian orogen, showing the location of the Talladega belt (fine stipple) and Figure 2. Coarse stipple-western Blue Ridge; plus pattern-eastern Blue Ridge; solid- Grenville basement (~1.1 Ga); FTB-foreland fold- and- thrust belt.

(Carozzi, 1989). Throughout the Ordovician as well, Laurentia is considered to have been at near equatorial latitudes in the southern hemisphere (Van der Voo, 1998). The Alabama recess (Figure 1), containing the Sylacauga Marble Group, is interpreted to have originated as an oceanward continental projection (promontory) that had the characteristics of an upper plate (distal) extensional margin during the opening of Iapetus and subsequent formation of the carbonate platform (Thomas, 1993). The entire carbonate platform represented by the Sylacauga Marble Group was subsequently detached during the late Paleozoic and emplaced by thrusting directly onto more inboard parts of the margin.

This study focuses upon the stratigraphy, depositional setting, and correlation of the Sylacauga Marble Group carbonate sequence within the Talladega belt. The Sylacauga Marble Group is the most distally known part of the post-Chilhowee Group passive margin drift facies that was deposited during Iapetan spreading, an interval of approximately 80 m.y. Surprisingly, in spite of diagenetic and low grade metamorphic alteration (350°- 400° C), which included recrystallization and variable strain, a number of primary depositional features are preserved within the marble sequence allowing for identification of several depositional facies and environments. Interpretations of depositional environments, although tentative in several places, are based upon observed and inferred sedimentologic features, rare paleontologic data, and stratigraphic relationships, as well as comparison with both ancient and modern analogues. These

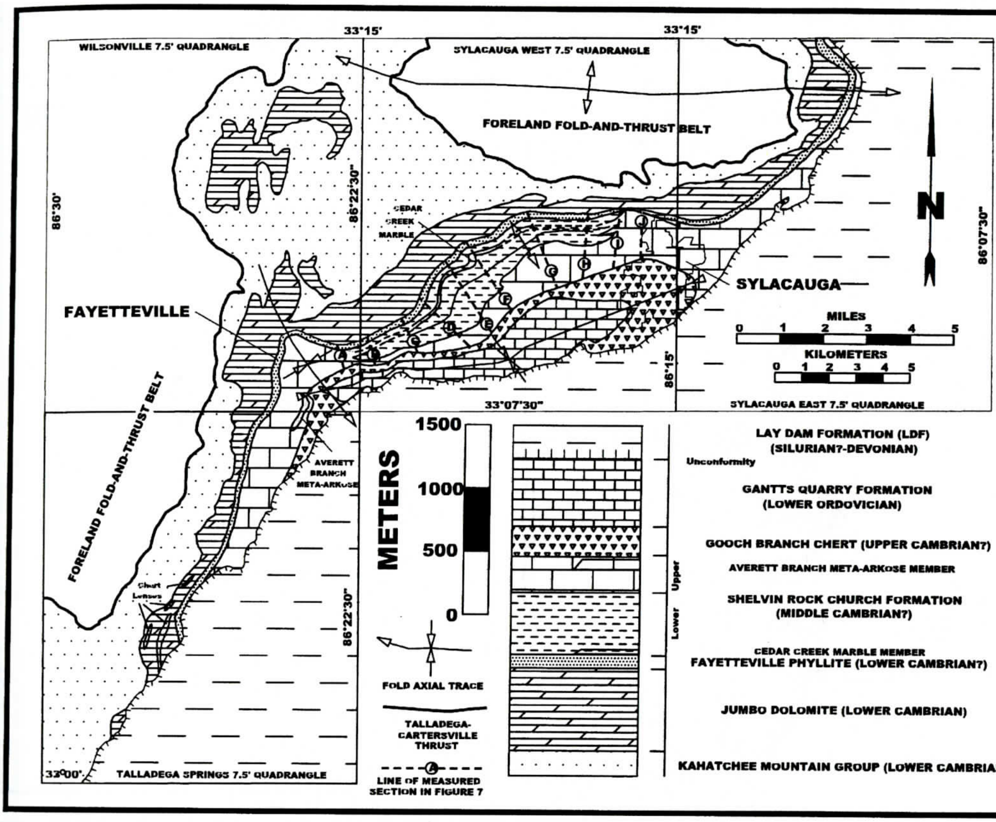


Figure 3. Geologic map of the Sylacauga Marble Group in the southwestern Talladega belt.

METAMORPHIC GRADE

Rocks within the Talladega belt contain lower greenschist facies mineral assemblages (Tull, 1985). Metabasaltic rocks plot within the *albite-actinolite-chlorite zone* of Winkler's (1976) lower greenschist facies (Tull and others, 1998), representing conditions within P-T space approximating 300°- 350° C and 3-4 kb (Bucher and Frey, 1994), and conodonts and phosphatic brachiopod (?) shards within metacarbonate rocks of the Sylacauga Marble Group have color alteration indices of 5.5 to 6, indicating temperatures of ~350°- 400° C (A. L. Harris and J. E. Repetski, written communication, 1984; Tull and others, 1988). In spite of these conditions of regional metamorphism, however, rocks of the Sylacauga Marble Group preserve a remarkable number of primary features. This is particularly true of the dolomitic marble units. Under the ambient metamorphic conditions in the region, on the other hand, strain was highly partitioned into the calcite marbles, which exhibit significant ductility, high strains, and only rare preservation of primary features.

STRATIGRAPHY AND DEPOSITIONAL ENVIRONMENTS OF THE SYLACAUGA MARBLE GROUP

Rocks of the Sylacauga Marble Group reach an aggregate thickness of >2 km, although the sequence is folded into an open syncline/anticline pair that is truncated by the overlying pre-Lay Dam Formation unconformity, so that much of the sequence is cut out along this unconformity (Tull, 1998). The maximum exposed thickness beneath this unconformity is located west of the city of Sylacauga (Figure 3). Lithologic variation allows the Sylacauga Marble Group to be divided into five mappable formations, including from bottom to top: Jumbo lishment of Iapetus sea floor (Simpson and Ericksson, 1989). The Kahatchee Mountain Group is overlain by a thick (>2 km), dominantly peritidal carbonate sequence, the Sylacauga Marble Group, the focus of this study, and is equivalent to the Lower Cambrian-Lower Ordovician Shady Dolomite-Knox Group of the Appalachian foreland to the northwest. Northeast of the central Talladega belt, the frontal fault cuts up-section into the Sylacauga Marble Group, completely eliminating the Kahatchee Mountain Group, and emplacing the Sylacauga Marble Group above carbonate units of the foreland (Figure 2). Fossil occurrences in the Sylacauga Marble Group are rare, but a well defined lithostratigraphy has been established, and lithostratigraphic correlations with the equivalent interval of rocks in the Appalachian foreland have been proposed (Shaw, 1970; Tull, 1985; Johnson, 1999).

Above a regional unconformity, which cuts both of the underlying sequences, is a younger siliciclastic sequence, the Silurian (?)-Lower Mississippian (?) Talladega Group (Tull, 1982; Gastaldo and others, 1993) (Figure 2). This group represents a >2.5 km thick successor basin sequence (clastic wedge) containing metaturbidites, arkosic conglomerates, and olistostromes in the lower part (Lay Dam Formation), and shallow-water metasandstone and metaconglomerate (Butting Ram-Cheaha Quartzite), metachert, black slate, and siliceous argillite (Jemison Chert-Erin Slate) in the upper part. These rocks were derived from erosion of the underlying lower Paleozoic shelf carbonate and clastic rocks, as well as the underlying granitic Grenvillian basement (Tull and Telle, 1989).

The southeast (upper) boundary of the Talladega belt is a regional footwall thrust duplex, the Hollins Line fault system, which is a large-displacement Alleghanian transpressional thrust system marking the eastern Blue Ridge-western Blue Ridge terrane boundary in this region (Tull, 1995) (Figure 1). Late Proterozoic, middle to upper amphibolite facies units of the eastern Blue Ridge southeast of the roof thrust of this duplex constitute part of a composite suspect terrane (Jefferson Terrane of Horton and others, 1991) that is not definitively linked stratigraphically to Laurentia. This fault system formed during the emplacement of the eastern Blue Ridge allochthon above the Talladega belt during the late Paleozoic Pangean collision.

Because of the high industrial quality marble in the Sylacauga area, part of the Sylacauga Marble Group has been the subject of several previous investigations. Early insightful studies by Smith (1888), McCalley (1897), Prouty (1916), and Butts (1926) focused on the structural and stratigraphic setting of the marble units. These studies generally concentrated on the strip of "crystalline marbles" (high-purity calcite marbles) on the southeast (top) of the sequence, and included these marbles as part of the Talladega belt stratigraphy, referring to them as the "Sylacauga marble member" (Butts, 1926). These geologists excluded the dominantly dolomitic carbonates below and to the west of the "Sylacauga marble member" from the Talladega belt, however, interpreting them instead as Cambrian-Ordovician carbonate units exposed within a window into the underlying foreland. In a structurally isolated area near Columbiana, within the core of the Jemison-Columbiana synform (Figure 2), however, Butts (1940) mapped units of the Sylacauga Marble Group as their foreland equivalents (Shady Dolomite-Conasauga Formation) and interpreted them as being in stratigraphic sequence above rocks now assigned to the Kahatchee Mountain Group (Tull, 1985; 1998).

The conformable nature of the "Sylacauga marble member" with the underlying dolomitic carbonate units was first suggested by Rodgers and Shaw (1962), and later detailed by Shaw (1970). Shaw (1970), like Prouty (1916), recognized that the Kahatchee Mountain Group is in stratigraphic contact with the overlying dolomitic carbonate sequence and, like earlier workers, suggested that these marbles were equivalent to Cambrian-Ordovician carbonate units to the northwest beneath the Talladega-Cartersville fault. Shaw (1970) also proposed that the marble sequence was overlain unconformably by the Lay Dam Formation, challenging the long-held idea that the contact was a fault.

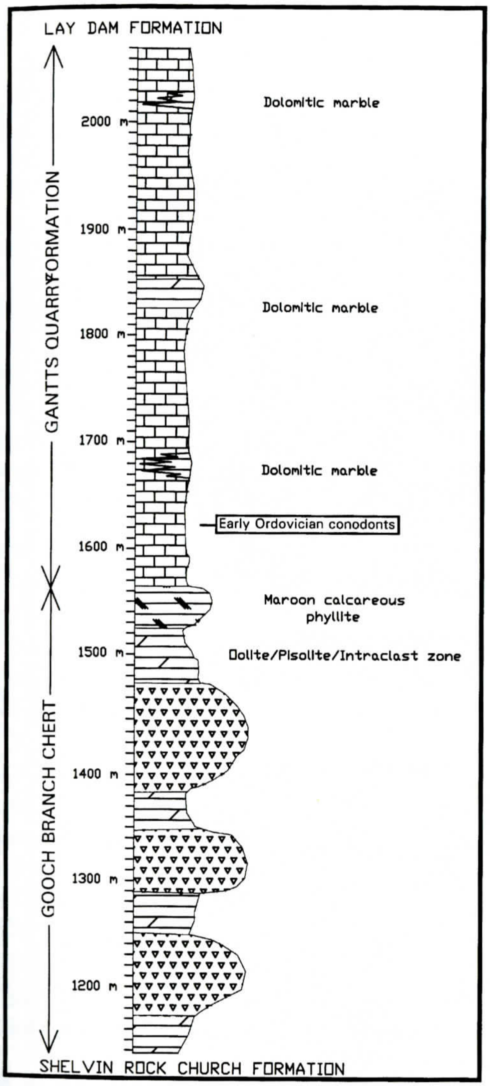


Figure 4C. Gooch Branch Chert and Gantts Quarry Formation.

of m thick) containing apparent dessication cracks or gas escape structures, tepee structures, and cemented laminoid and irregular fenestrae (Figure 5B). Other elliptical structures in this section of the Jumbo occur in finely laminated marble and contain geopetal features (Figure 5C), indicating that micrite was deposited at the base of the originally hollow features. These structures are probably dissolved pisoids/oöids or peloids. The overlying upper Jumbo section (100-200 m thick) is massively bedded, and contains ubiquitous oncoids, pellets, algal/cryptalgal-coated grains, grains composed of coated-grain calcarenite, micrite, pelletal micrite, echinoderm plates, and possible trilobite fragments, as well as archaeocyathids (Tull and others, 1988). Massive metachert ridges within the Jumbo Dolomite locally crop out above the floor of the marble valley (Figure 3). These metacherts are penetratively deformed, lack relic primary features, and appear to be discontinuous lenses near the middle of the unit.

Exposures of the Jumbo Dolomite near Jumbo (Figure 2) are within the lower 60 m of the unit and represent the most palinspastically outboard (southeast) exposures of the unit. Here, Pendexter (1982) described poorly sorted and randomly oriented, matrix-rich, polymictic carbonate breccias (Figure 5D) forming layers 1-1.5 m thick in the lower 10 m of the unit. This section also contains synsedimentary slump folds.

Paleontology

The age of the Jumbo Dolomite has been established as Early Cambrian, on the basis of the presence of archaeocyathids (Figure 6) near the top of the unit near Fayetteville (Figures 3 and 4) (Tull and others, 1988). The most abundant forms belong to Class *Irregulares*, Order *Archaeocyathida*. Others belong to the Superfamily *Tumulocyathacea*, Class *Regulares*, Order *Ajaicicyathida*. The age assignment of these fossils is based on their exclusive occurrence in Lower Cambrian rocks in North America. The fossils also limit the age of the underlying unfossiliferous Kahatchee Mountain Group. At a locality south of Winterboro (Figure 2), the uppermost Jumbo/lowermost Fayetteville Phyllite yielded phosphatic fragments of probable brachiopod shards.

Interpreted Depositional Environments

Much of the lower Jumbo Dolomite is thinly laminated, fine-grained, dolomitic marble with carbonate laminations separated by very thin quartz silt laminations. The thin laminations most likely represent micritic, intertidal, algal

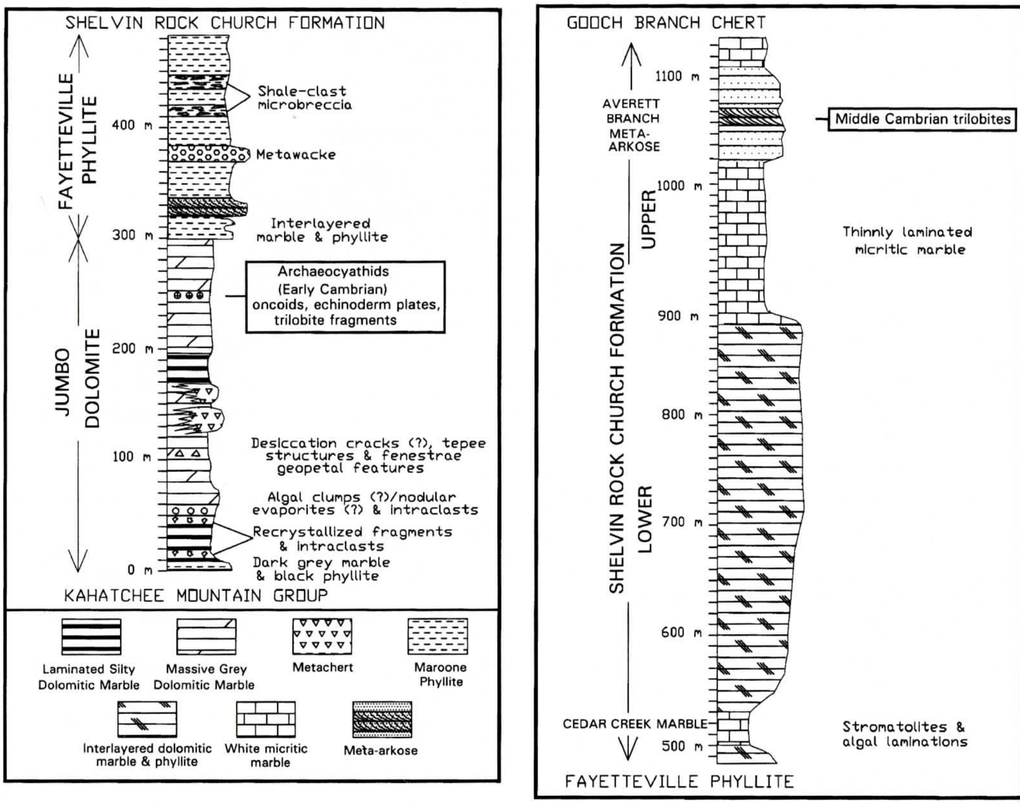


Figure 4. Stratigraphic column of the Sylacauga Marble Group: A) Jumbo Dolomite and Fayetteville Phyllite; B) Shelvin Rock Church Formation; C) (next page) Gooch Branch Chert and Gantts Quarry Formation.

Dolomite, Fayetteville Phyllite, Shelvin Rock Church Formation, Gooch Branch Chert, and Gantts Quarry Formation (Figures 3 and 4). The presence of an unconformity at the top of the sequence, and primary facing and paleontological data within the sequence indicate that the sequence is in stratigraphic order.

Jumbo Dolomite

Description

The Jumbo Dolomite (Figures 3 and 4A) conformably overlies and is interbedded on a decimeter scale with uppermost carbonaceous calcareous phyllites of the siliciclastic Kahatchee Mountain Group. The top of the Jumbo is interbedded with the overlying Fayetteville Phyllite. The unit averages approximately 300 m in thickness but ranges to over 600 m. The basal section (~50 m) consists of thin laminations (0.2-1.0 mm thick) of light to dark gray, finely crystalline marble, separated by thin silt layers (0.02-0.25 mm thick). The marbles in this section locally contain disseminated silt- to well-rounded coarse sand-size quartz grains (up to 17 modal %) in addition to interbedded layers of calcareous sandstone as much as 15 cm thick.

Overlying the thinly laminated carbonates at the base of the Jumbo is ~120 m of massively bedded, gray to light gray dolostone. Northeast of Fayetteville (Figure 3), this interval locally contains irregularly shaped, 1 mm to 2 cm ovoid masses within a darker gray matrix (Figure 5A). These features lack preservation of internal microstructures and superficially appear to be pebbles in a carbonate conglomerate, but, they are more likely either "algal clumps" (Johnson, 1961) or nodular evaporates. This zone is overlain by very thinly laminated (<1-3 mm thick), light to dark gray dolomitic marble (several 10s

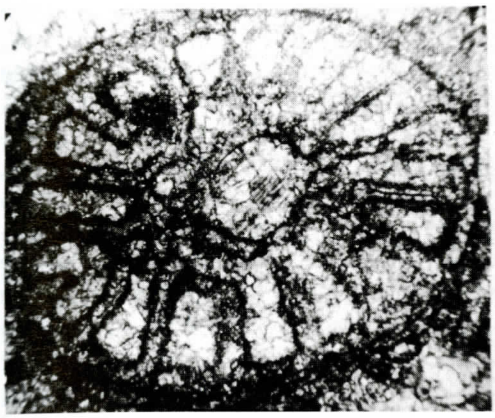


Figure 6. Photomicrograph of Irregular Archaeocyathid from the Jumbo Dolomite. Long dimension of photo is 3.2 mm

laminations formed within an algal tidal-flat (Tucker and Wright, 1990). This interpretation is supported by the presence of possible algal "clumps" or nodular evaporites, and dessication cracks or gas escape structures, tepee structures, and (now cemented) fenestrae in probable cryptalgal laminite in the lower Jumbo. The dessication cracks, tepee structures, and fenestrae indicate extended periods of exposure and thus an intratidal or supratidal environment (Hardie and Ginsburg, 1977; Tucker and Wright, 1990).

Layers of calcareous sandstone and siltstone near the base of the unit formed as the carbonate platform was in its initial developmental stages and probably represent episodic influxes of clastic sediment from the craton, and/or episodic, minor regressions resulting in progradation of siliciclastic sediment out onto the newly forming carbonate bank (Wilson, 1975). The well rounded medium to coarse quartz sand grains may be aeolian grains from a nearby beach environment, representing the transition from the clastic-dominated Kahatchee Mountain Group to the carbonate-dominated Sylacauga Marble Group. Marbles in the upper two thirds of the Jumbo are generally massively bedded and lack the thinly laminated micrite of the lower part. The zone near the top of the unit containing archaeocyathids, oncoids, pellets, and algal/cryptalgal-coated grains represents a warm, shallow-marine, moderate energy environment. Thus, all observed primary features recognized indicate that the majority of the Jumbo is peritidal (shallow-marine to supratidal) in origin.

The Kelley Mountain antiform has exposed isolated sections (as much as 60 m thick) of the basal Jumbo Dolomite west of the Coosa River, near Jumbo (Figure 2). The ~24° plunge on this regional structure (Tull and Telle, 1989) indicates that exposures near Jumbo, near the hinge of the fold, are ~16 km down dip (i.e., perpendicular to regional strike) from most Jumbo exposures examined in the main marble belt to the northeast. This area contains unique features of the Jumbo, including soft-sediment folds and polymictic carbonate breccia (Figure 5D) (Pendexter, 1982). The polymictic breccia contains thinly laminated, randomly oriented, angular clasts of dark mudstone of various sizes (as much as 10 cm long) suspended in a dark dolomitic matrix. Many of the clasts contain fenestrae and resemble fenestral laminites formed as intertidal mud flat deposits, similar to more palinspathically inboard exposures of the Jumbo (Figure 5B), but unlike that in the enclosing dolomitic marble. Thus, the clasts were probably derived from an intertidal facies of the Jumbo exposed to the northwest. These breccias closely resemble carbonate debris flow deposits (Pfeil and Read, 1980; Read and Pfeil, 1983; Scholle and others, 1983), and were probably triggered by slope failure on a high-angle paleoslope. Soft-sediment folds found at this locality also suggest deposition on a paleoslope. Because these exposures are across structural and probable depositional strike to the southeast of other lower Jumbo exposures, they may represent the only exposures from the carbonate sequence that are representative of a deep-water ramp facies or debris apron containing resedimented carbonate rocks (Scholle and others, 1983). The poor sorting of the debris flows can be explained by limited transport as sediment gravity flows down the paleoslope (Pfeil and Read, 1980). If a carbonate ramp or platform rim separated the exposures of the unit at Jumbo from the more shallow-water shelf facies to the northeast, then it has apparently been cut out by erosion along the pre-Lay Dam Formation unconformity south of Marble Valley (Figure 2).

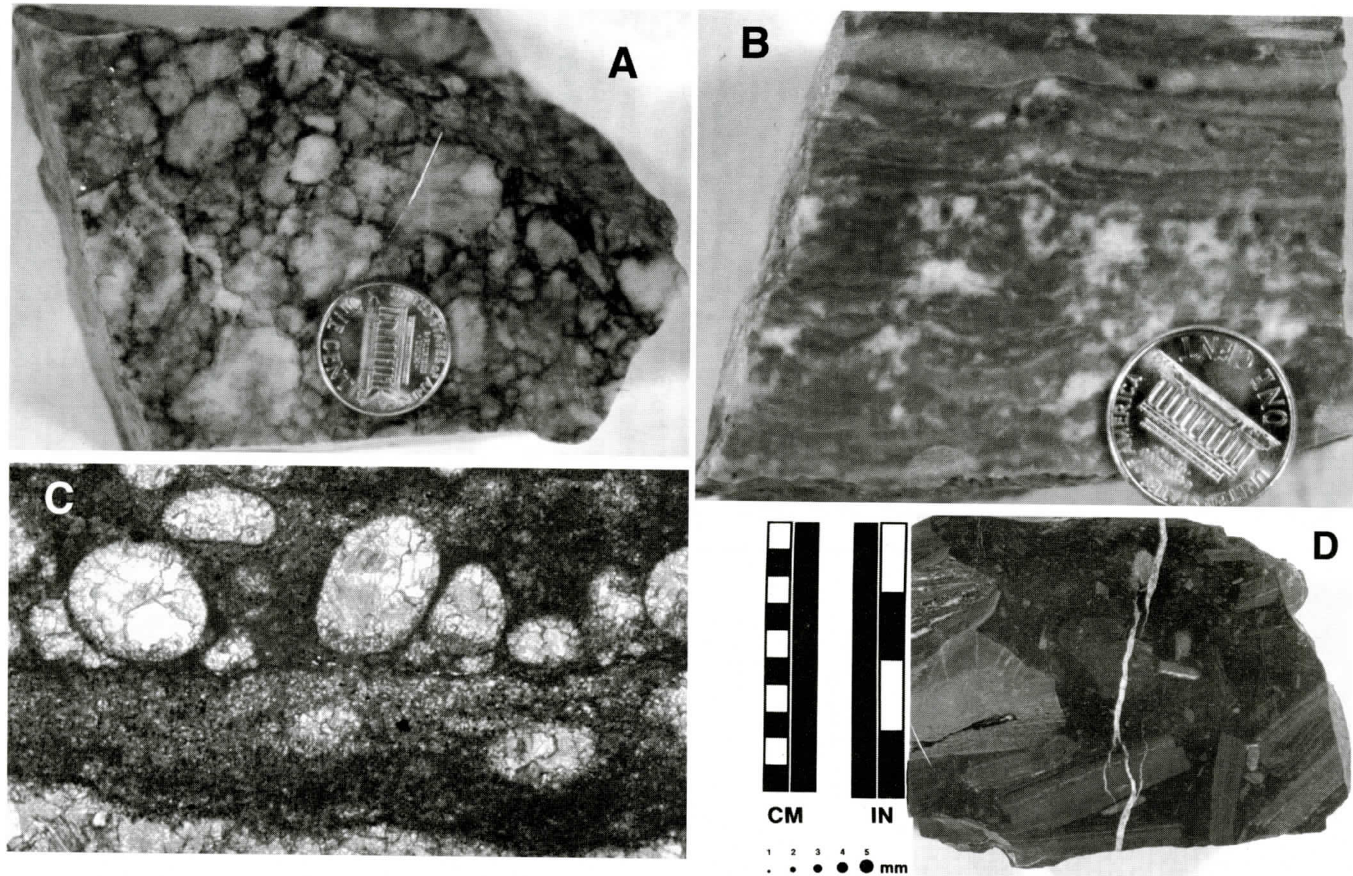


Figure 5. Primary features from the Jumbo Dolomite: A) Polished slab showing possible algal "clumps" or, alternatively, nodular evaporites in lower Jumbo Dolomite; B) Polished slab showing possible dessication cracks or gas escape features, calcite-cemented irregular fenestrae (white), and tepee structures in Jumbo Dolomite cryptalgal laminite (?); C) Photomicrograph of elliptical structures (probably dissolved pisoids/oöids or peloids) in finely laminated Jumbo Dolomite. These once-hollow structures contain fine-grained micrite within the bottom interior forming geopetal features. Long dimension of photo is 1.8 mm.; D) Polished slab of polymictic carbonate slope (?) breccia from Jumbo Dolomite at Jumbo.

ly exposed during low tide. Erosion of the resulting desiccation cracks with the return of high tide produces mudclasts. No desiccation cracks have been observed in the generally poorly exposed phyllites, but mudclast (micro) breccias are common indicators of desiccation (Miall, 1990). The fine-scale laminations intercalated with the microbreccia facies indicate periodic alternation between the two depositional regimes and support the desiccation crack hypothesis. A transition from quiet to turbulent water during episodic storms could also have generated the microbreccia, where pieces torn from the mud substrate could form rip-up clasts. Microbreccias produced by either of the above mechanisms form under shallow-water conditions.

The fine-grained metaarkose facies, containing small-scale, mud-coated cross laminations and both symmetrical and asymmetrical ripple marks, provides additional evidence for shallow-water deposition of the unit. Both primary features are indicative of shallow-water, current-driven environments. Taken together, the potential desiccation-produced microbreccia in otherwise laminated metamud and siltstone, with the combination of mud-coated symmetrical and asymmetrical ripples and cross stratification, suggest a tidal-flat environment for much of the Fayetteville. In this context, the thicker units of fine-grained metaarkose likely represent subtidal sand shoals or bars. The localized, poorly sorted metagraywacke facies may represent a slump feature or debris flow within a low spot, such as a tidal channel, which cut into the tidal-flat facies.

McReynolds and Driese (1994) presented a model explaining the synchronous deposition of carbonates, shales, and sandstones of the Rome Formation that may be applicable to the Fayetteville Phyllite. Their depositional model of the Rome Formation in the Tennessee Appalachians explains how the geometry of the underlying Shady Dolomite influenced the deposition of the Rome. Undulations on the surface of the Shady carbonate bank created a "patchwork" sedimentation effect. Thus, different types of siliciclastic sediments, along with some carbonate sediments, were deposited synchronously in small patches, creating abrupt and common facies changes. The Fayetteville is lithologically and depositionally similar to the Rome and has a similar age/stratigraphic position within the carbonate platform (see below).

Shelvin Rock Church Formation

Description

The lowest marble stratigraphically above the Fayetteville Phyllite marks the base of the Shelvin Rock Church Formation. This unit conformably and gradationally overlies the Fayetteville. Ranging between 600 and 1000 m in thickness, it is the thickest unit of the Sylacauga Marble Group and contains the most diverse lithologies. It is separated into lower and upper sequences, each containing a differentiated member.

Lower Shelvin Rock Church Formation

The lower Shelvin Rock Church Formation (Figures 3, 4B, and 7) is a lens-shaped mixed carbonate-siliciclastic unit extending 10.5 km along strike. It consists of a series of variably thick (a few centimeters to one meter) marble layers cyclically interbedded with dark charcoal to maroon phyllite (generally a few centimeters thick, but ranging from <1 mm to 0.5 m thick) (Figure 8A). The subunit reaches a maximum thickness of ~ 700 m, 5 km west of Sylacauga, progressively thinning toward the northeast and southwest (Figure 7). The lateral transition from the lower subunit to lithologies of the upper subunit (see below) is not well exposed but appears to involve intertonguing of lithologies representative of both subunits. Typical marble layers within the lower Shelvin Rock Church range from white, pink, to dark gray; are medium to coarsely crystalline; and are commonly dolomitic. They commonly contain finer-scale beds and laminations (a few mm thick), and locally contain minor disseminated (<1%) quartz sand/silt. Many of the thinner marble beds are lenticular in form. Both upper and lower contacts of marble layers are sharp. On average, phyllite constitutes 20 percent to 30 percent of

Fayetteville Phyllite

Description

The Fayetteville Phyllite conformably overlies sandy argillaceous marble at the top of the Jumbo Dolomite (Figures 3 and 4A) and is predominantly a maroon to charcoal-purple phyllite, 80 m to 290 m thick. Interlayered with the fine-grained pelitic rocks are tan metasiltstone, and yellowish-brown to ochre, thinly bedded, very-fine to fine-grained, micaceous arkosic metasandstone. The porous, low-density tan metasiltstone apparently once contained a significant proportion of calcareous mud, but most of the carbonate has been leached from surface exposures. The charcoal-purple and maroon phyllites are commonly strongly foliated and lineated, much more so than the tan phyllites, and contain numerous 1-2 cm, eliptical chlorite segregations. The various phyllites appear to grade laterally into one to another, and discontinuities in topography and outcrop of the unit suggest that the metapelite facies may also grade laterally into carbonate rocks. A distinctive lithology within the phyllite facies is clast-dominated microbreccia containing ~70 percent angular lithic clasts (0.1-7 mm in long dimension) interlayered with dark, charcoal-gray, mm-scale, laminated phyllite. The lithic clasts are of three types: a) dark brown metashale (mud) fragments very similar to the matrix (~8 vol. %) b) light beige metashale clasts (~54 vol. %) and c) metasiltstone clasts (~7 vol. %). The high clast-to-matrix ratio suggests that the rock was originally clast supported.

Metaarkose within the Fayetteville is thinly bedded (2-20 cm scale) and finely laminated (mm scale), is locally cross laminated (sets ~15 cm thick), and contains both wave current (oscillation) ripple and current ripple marks (Leeder, 1982). Individual sandstone beds are laterally continuous and are commonly separated by thin phyllite partings. A continuous interval, 20 to 30 m thick, of well-sorted, fine- to very fine-grained metaarkose (quartz- 49.3%, K-feldspar- 41.6%, plagioclase- 2.3%, calcite- 4.6%, mica-0.6%, and opaque minerals- 1.3%, plus trace zircon and tourmaline) is found within the Fayetteville near Winterboro (Figure 2). Dip-corrected cross laminations indicate paleocurrent directions between 126° and 141°, whereas wave current ripples indicate a current direction of 200°.

Near Fayetteville, an isolated lens of metagraywacke, containing a very fine-grained, gray-blue matrix (64.5 %) consisting of chlorite, sericite, and quartz silt is interbedded within the phyllite facies. Suspended within the matrix are rounded, mono- and polycrystalline quartz sand grains (35.5%) 1-1.5 mm in diameter.

Interpreted Depositional Environments

The transition from the carbonate-dominated Jumbo Dolomite to the siliciclastic-dominated Fayetteville Phyllite represents an extensive, platform-wide change in sediment composition and depositional environment. Probable lateral facies transitions into carbonate rocks within the Fayetteville suggest, however, that carbonate sedimentation along the platform may not have completely ceased during deposition of the unit. Such an influx of siliciclastic sediment from a terrestrial source, like the craton, must prograde out onto the carbonate platform, and be great enough to choke out most carbonate deposition and firmly establish sliciclastic deposition. This could be achieved by uplift of siliciclastic-source rocks and/or progradation of fine siliciclastic sediments out onto the carbonate platform as a result of sea-level fall.

Several of the preserved primary features in the Fayetteville suggest shallow-water deposition. For example, the siltstone clasts in the microbreccia lithofacies were probably eroded and deposited locally, preserving their angularity and lack of sorting. The other two clast types (shale/mud clasts), similar to the lithologies representative of most of the fine-grained phyllite of the Fayetteville, may have been derived during punctuated or periodic erosional events due either to exposure or storm events, followed by shale/mud deposition in shallow tidal-flat channels (Elliott, 1986). A common mudclast-producing mechanism is desiccation within a tidal-flat setting where mud becomes subaerial-

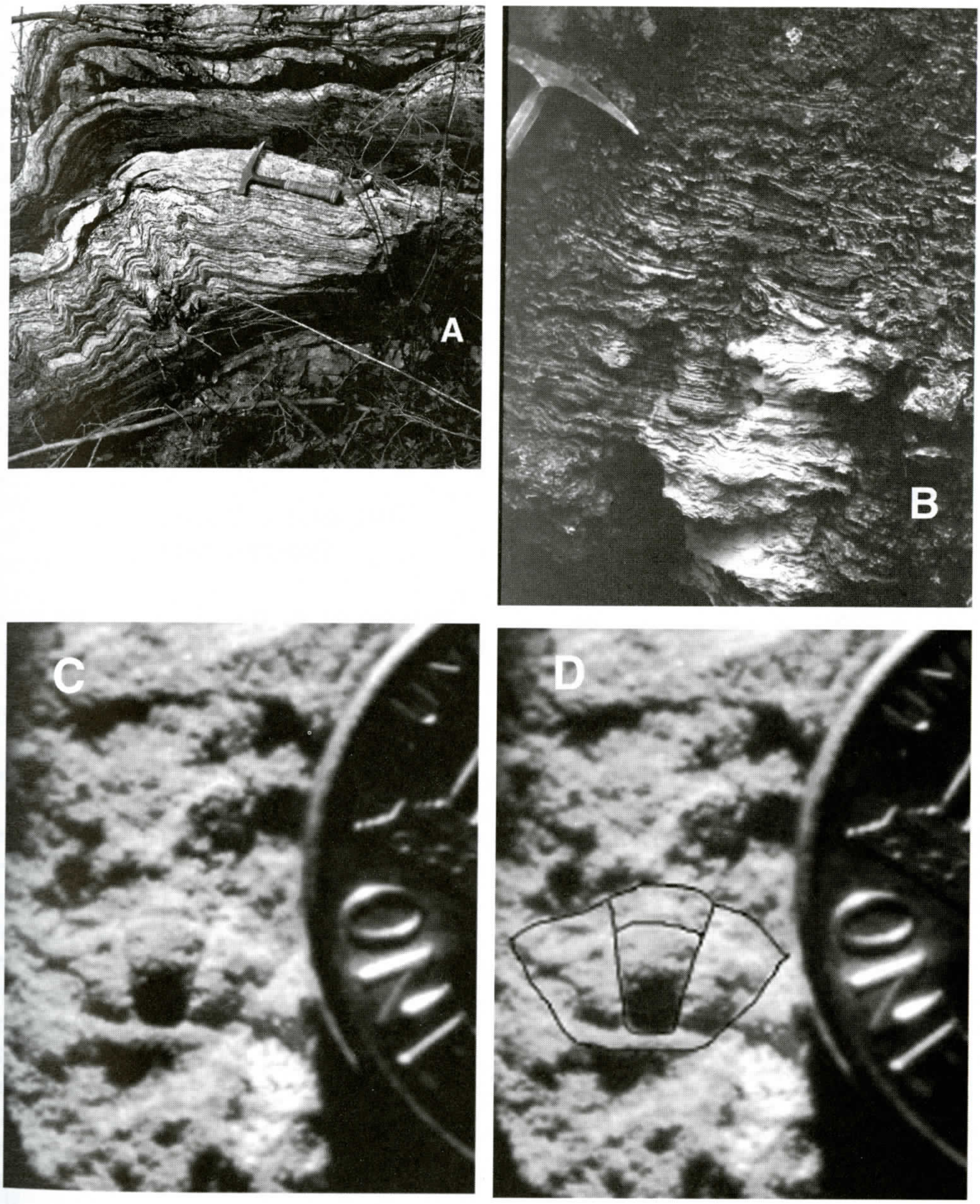


Figure 8. A) Folded laminated dolomitic marble (light) and interlayered phyllite (dark) of the lower Shelvin Rock Church Formation; B) Outcrop photograph of wavy stromatolitic (?) laminations from the Cedar Creek Marble Member, lower Shelvin Rock Church Formation; C) Trilobite *Soleno-pleurella? sp.* from Averette Branch Metaarkose Member, upper Shelvin Rock Church Formation; D) Same as c, but enhanced with outline of cranadial and glabella.

lite (Figure 7). The vertical transition from the phyllite/marble interbedded facies into the overlying thinly laminated marbles is abrupt.

The Averett Branch Metaarkose Member (formally named here for exposures along Averett Branch, 1 ¾ km southeast of Fayetteville) (Figures 3 and 4B) is a thick metasandstone lens within the thinly laminated marbles of the upper Shelvin Rock Church. It is a well sutured, well sorted, fine-grained (0.5 mm), tan to pink, arko-

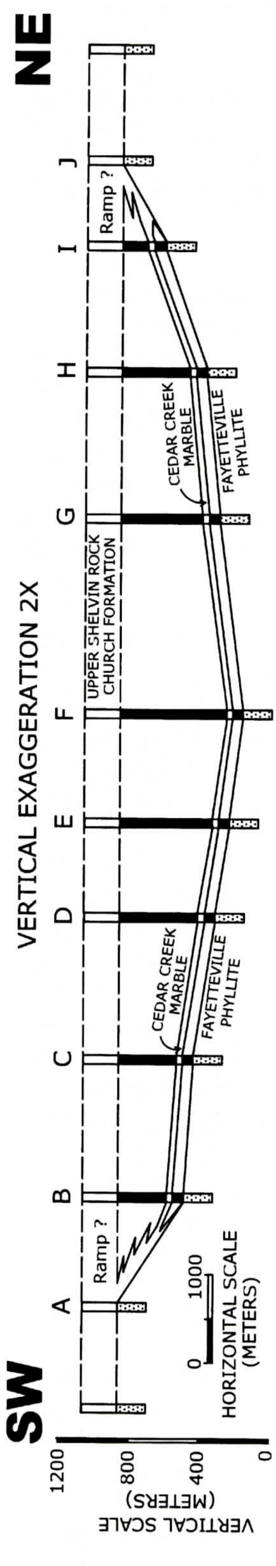


Figure 7. Lower Shelvin Rock Church Formation intrashelf basin compiled from lines of sections shown in Figure 3. Cyclic carbonate/siliciclastic facies of the lower Shelvin Rock Church Formation-solid pattern.

this part of the formation. Reasonable values of differential compaction (80%) suggest that the mudstone protoliths of the phyllites may have originally constituted from 36 percent to 54 percent of this lower interval. In addition to phyllite, nonmarble layers include metasiltstone, and locally, thin, fine-grained, feldspathic metasandstone. Because the phyllites are more resistant to erosion than the surrounding carbonates, the lower Shelvin Rock Church Formation commonly forms low ridges throughout its extent.

The Cedar Creek Marble Member (formally named here for cliff exposures along Cedar Creek, 7 km west of Sylacauga) (Figures 3 and 4B) is a 30-m thick calcite and dolomite marble near the base of the lower Shelvin Rock Church Formation. It is characterized by marble containing internal thin wavy, crinkly and undulate (Figure 8B) micritic laminations, typically 1-5 mm thick, but ranging to 1 cm. Unlike other parts of the lower Shelvin Rock Church above and below, the Cedar Creek has very few (less than 0.5 %), thin (<5 mm) phyllite interbeds. Fine quartz silt and muscovite "films," 0.05-0.1 mm thick, separate the micritic laminations, and are commonly no thicker than the dimensions of a single silt grain.

Upper Shelvin Rock Church Formation

The upper Shelvin Rock Church Formation (Figures 3 and 7) is found above and at the lateral limits of the lower part of the formation, and consists predominantly of coarsely crystalline, thinly laminated (0.5 mm to 1 cm thick) and banded (1 m thick), dove grey and white, calcitic/dolomitic marble containing disseminated coarse- to very coarse-grained, rounded quartz sand grains. Locally, the quartz sand is concentrated into tabular calcareous sandstone beds 1 to 4 cm thick. The unit also contains minor (1% to 3 %) quartz silt and muscovite in very thin, discontinuous laminae, similar to the Cedar Creek Marble. Beyond the northeast and southwest extents of the lower Shelvin Rock Church sequence, the upper Shelvin Rock Church rests directly on the Fayetteville Phyla specific area. Carbonate layers interbedded with the phyllites may have been composed dominantly of ribbon grainstones that formed in somewhat deeper water than the adjacent phyllite-free carbonates. A mechanism for deposition of the lower Shelvin Rock must be invoked that would restrict siliciclastic mud and silt sedimentation to only part of the basin, leaving the rest mud-free. One such mechanism could have involved an extrabasinal distribution system that channeled fine siliciclastic sediments across the platform into tectonically driven topographic depressions, to areas now represented by the intrashelf depocenter. Astini and others (2000) suggested that a similar (and probably correlative, see below) mixed carbonate-siliciclastic facies in the Conasauga Formation in Alabama may have resulted from either: a) productivity cycles; b) high frequency sea-level oscillations involving clastic input and carbonate retreat; or c) event cycles. The relatively regular cyclicity of the carbonate/siliciclastic interval in the Shelvin Rock Church suggests a combination of the first two mechanisms. Beyond the rim (ramp?) of the intrashelf depocenter elevations were likely high enough not to be affected by either of these possible fluctuations, and thus would have maintained more constant shallow-marine carbonate deposition. Unfortunately, the lateral transition between the upper and lower parts of the formation is very poorly exposed, but probably represents a carbonate ramp between the peritidal platform and intrashelf basin. Except for a short period of stability during which the Cedar Creek Marble was deposited across the basin, differential subsidence, probably in combination with fourth- and fifth-order sea-level oscillation cycles, apparently kept the basin deep enough to form the cyclically interbedded phyllite/carbonate facies. Eventually, however, subsidence ceased, probably as a result of cessation of fault movement, and the depositional environment was maintained as shallow-marine. At this point, thinly laminated marbles of the upper Shelvin Rock Church were deposited continually across the basin. A common attribute of carbonate platforms is that they are able to quickly fill in structural relief by progradation and basin-filling once synsedimentary faulting has ceased (Schlager, 1992).

Intrashelf depocenters similar to that proposed here for the lower Shelvin Rock Church Formation have been recognized in the Conasauga Group of the Appalachian foreland (Markello and Read, 1982; Hasson and Haase, 1988; Thomas and others, 2000). These intrashelf depocenters, however, are much broader and the deposits are thinner and more shale-dominated. Nevertheless, they do display carbonate/shale interbeds similar to the lower Shelvin Rock Church. Because the latter formation is homoclinally dipping, however, it is possible that this basin represents one edge of a larger basin, most of which is not exposed.

The Cedar Creek Marble apparently represents a short hiatus in differential subsidence of the intrashelf basin, because it is overlain by the main sequence of cyclically bedded siliciclastic/carbonate rocks of the lower Shelvin Rock Church Formation. The fine laminations of the Cedar Creek consistently exhibit a wavy or crinkled appearance (Figure 8B) suggesting algal or stromatolitic laminations (Scholle and others, 1983), and the unit is therefore interpreted to contain cryptalgal laminite or stromatolites. The small surface relief features are believed to have been caused by microbial mats that accumulated on and below the sediment surface. Such features can allow for distinction between microbially colonized tidal flat surfaces and purely sedimentary laminated sediments (Tucker and Wright, 1990). The depositional setting of the Cedar Creek was therefore probably one where thin micrite laminations formed under relatively quiet, peritidal (supratidal?) conditions in which carbonate mud was bound to the substrate by algal mats (Tucker and Wright, 1990). The fine quartz silt and muscovite "films" separating the micritic laminations occur in regular, thin laminae and are not mixed with the micrite. Because the siliciclastic "films" are distinct from the micritic laminae, it is likely that some depositional process in addition to the background carbonate sedimentation is responsible for their occurrence. If algae had bound these sediments along with carbonate mud from the water column, mixing of the sedsic to subarkosic arenite containing quartz (66.3%-78.9%), K-feldspar (19.1%-31.5%), and trace amounts of detrital muscovite, biotite, zircon, and tourmaline, with little or no matrix. It extends along strike for approximately 2.4 km, reaching a maximum thickness of approximately 86 m. The porous nature of the rock suggests that it may have contained a carbonate cement, a likely scenario considering that it is stratigraphically surrounded by carbonate rocks. The sandstone contains thin, delicate laminations (<1 mm to 5 cm thick), indicating that the unit was not significantly bioturbated. It also contains upright crossbeds, but only three sets have been found in place. Rotations involving unfolding and rotation of topset beds to horizontal yield paleocurrent directions of 82°, 270°, and 304°.

Paleontology

The Averett Branch Metaarkose Member contains poorly preserved trilobite cranidia as casts and molds along bedding planes. Because the grains creating the casts and molds are sand-sized, many of the finer details of the original fossils are lost, and most do not have enough detail to be identified at the species level. The casts and molds do, however, preserve some recognizable forms, as well as different sizes and shapes that represent different genera and maturity stages of trilobites. Two species, on the basis of shape and structure of cranidial casts, have tentatively been identified as *Solenopleurella? sp.* (Figure 8C, D) and *Elrathia* cf. *E. antiquata* (David R. Schwimmer, written and oral communication, 1998). *Solenopleurella? sp.* is Middle Cambrian in age, whereas *Elrathia* cf. *E. antiquata* ranges from Middle to Late Cambrian and is not as useful for biostratigraphic work as *Solenopleurella?* sp. (David R. Schwimmer, written and oral communication, 1998). *Solenopleurella?* sp. is a very common species throughout the Consauga Formation of the Appalachian foreland (Schwimmer, 1989). The fact that cranidial morphologies resembling *Solenopleurella*? sp. and *Elrathia* cf. *E. antiquata* were found together in the same unit strengthens the likelihood that both identifications are correct (David R. Schwimmer, written and oral communication, 1998). There are also numerous trilobite species in the Averett Branch Metaarkose that cannot be identified. Schwimmer (written and oral communication, 1998) believes that several very small cranidia (~3-4 mm across) are from a type of planktonic trilobite called *Agnostida*. Unfortunately, these trilobites require exceptional preservation for species identification, a necessity for biostratigraphic work. There are other fossils within the Averett Branch member that cannot be identified, but many are likely trilobite fragments. One prevalent unidentified nontrilobite fossil has an irregularly shaped honeycomb-like structure 1-3 cm across.

Interpreted Depositional Environments

Metamorphic recrystallization of the interbedded marbles and phyllites has obscured any original primary features other than bedding in the lower Shelvin Rock Church. The outcrop distribution of this part of the unit (Figures 3 and 7) suggests that deposition of the mixed carbonate-siliciclastic facies was restricted to a specific area of the carbonate platform. The Cedar Creek Marble Member and the upper Shelvin Rock Church Formation are phyllite-free and thus represent a different depositional setting. The thickness variations in the lower Shelvin Rock Church Formation (Figure 7) are interpreted to be the result of an intrashelf depocenter, or basin, which underwent periodic differential subsidence relative to the basin flanks. In comparison to the laterally adjacent shallow-marine carbonates of the upper Shelvin Rock (see below), the phyllite interbeds, deposited as siliciclastic mudstones, siltstones, and locally, very fine-grained sandstones, probably represent a relatively deeper-water facies. This localized deposition of relatively deeper marine siliciclastic sediments adjacent to shallow-marine carbonates is best explained by the presence of an intrashelf depocenter, the location of which was possibly controlled by syndepositional faults. Such a setting also accounts for why extensive siliciclastic mud (phyllite) deposition was not basin-wide, but was restricted to

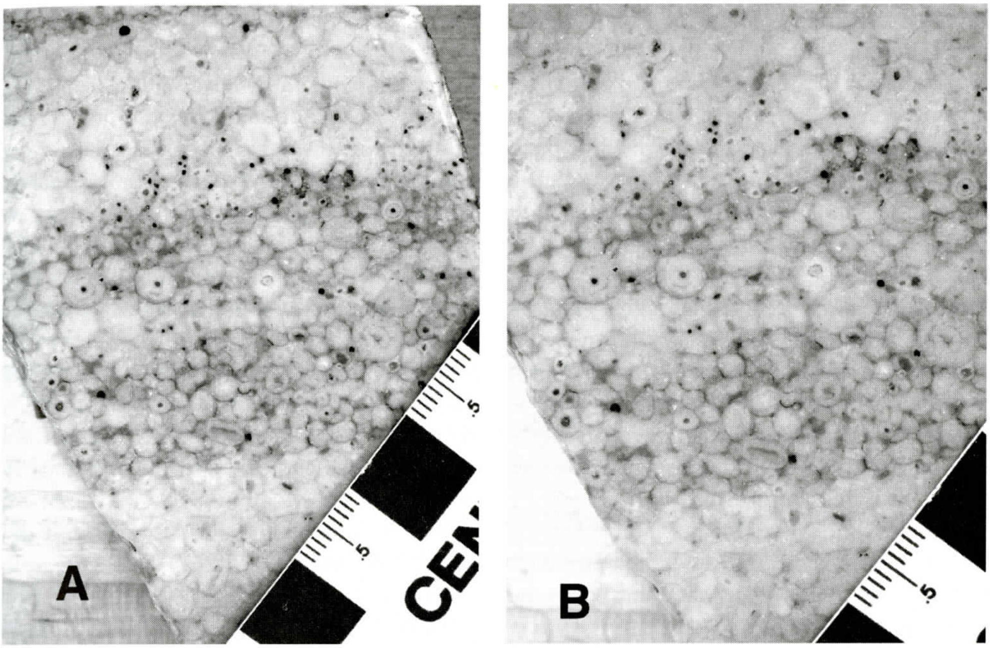


Figure 9. A) Polished slab showing bedded pisoids (oöids?) of various sizes from the Gooch Branch Chert. Bedding approximately parallels short dimension of photo. Black nuclei are micrite; grey nuclei are quartz. Fine scale in mm; B) Close-up of (A). Fine scale in mm.

"pisoid" (>2 mm diameter) are used in reference to coated grains with a concentrically laminated calcareous cortex and a nucleus of variable composition (Tucker and Wright, 1990). Some of the oöids/pisoids are oblong and irregularly shaped, in part because of irregularly shaped cores, but mostly as a result of flattening. Above and below the 20 m thick oöid/pisoid zone is medium- to coarse-grained crystalline dolomitic/calcitic marble with <1% disseminated fine- to medium-grained quartz sand like that forming the nuclei of many of the oöids/pisoids. The oöids/pisoids range from 1 to 5 mm in diameter, and have nuclei 0.5-3 mm in diameter (majority 0.7-0.8 mm). The nucleus of each is surrounded by cortex of diagenetically and/or metamorphically recrystallized medium-grained, twinned, rhombic calcite/dolomite crystals formed in faint spherical concentric laminations (0.25-1 mm thick) about the nucleus. Four different nuclei types are recognized in order of abundance: a) sub-spherical, highly organic peloids, probably originating as either algal peloids or fecal pellets; b) yellowish fine-grained carbonate fragments, probably recrystallized skeletal fragments; c) rounded to subrounded, monocrystalline quartz sand grains, 0.7-0.8 mm in diameter; and d) siltstone lithic fragments, 0.7-1 mm X 0.7 mm. Some of the nuclei are voids; secondary calcite spar grows freely into the void, a likely result of dissolution of the original nuclei. In other examples, two separate grains form the nucleus. Uncoated sand grains and dark micritic balls (peloids?) can also be found floating independently between the oöids/pisoids. Very fine calcite/dolomite crystals, probably representing a recrystallized primary micritic matrix, occur between the oöid/pisoid grains.

The presence of primary matrix between the oöids/pisoids, the fact that the oöids/pisoids appear to be sorted by size into different layers and contain a variety of nuclei types, and the presence of concentric laminations within many of the oöids/pisoids, suggest that these features are primary. None of the distinctive characteristics of vadose pisoids have been observed, and thus the pisoids are interpreted as coated grains that originated at the seafloor surface and apparently accumulated as a packstone. Recrystalliiments would be expected. The regularity and close spacing of the laminations indicate that the change in deposition occurred systematically and frequently. Fine-grained siliclastic sediments such as these are typically deposited in greater amounts if they are transported by terrestrial water currents. The silt and finer siliclastic grains within the Cedar Creek are in such delicate thin laminations, however, that it seems unlikely they were deposited by a current with a regular siliciclastic sediment load. The fact that the predominant component of the sediments is carbonate supports this assumption. A reasonable interpretation is that the quartz silt and clay "films" are wind-blown deposits, suggesting that these stratiform cryptalgal sheets were exposed during low tide.

The upper Shelvin Rock Church Formation, represented predominantly by a homogeneous lithofacies of laminated and banded marble, was deposited under relatively uniform conditions. The fact that much of this coarsely crystalline marble sequence also contains disseminated coarse- to very coarse-grained rounded quartz sand grains, locally concentrated into tabular calcareous sandstone beds suggests that it may have originally consisted of grainstone and/or packstone layers. Thin, millimeter-scale laminations, interlayered with thicker, centimeter-scale layers of fine grainstone or packstone, like those found in this part of the formation, are often associated with peritidal carbonate deposits (Tucker and Wright, 1990).

The mechanism for depositing enigmatic sand bodies like the Averett Branch Metaarkose Member within carbonate units like the upper Shelvin Rock Church Formation is unclear. The feldspar and trace minerals (zircon, tourmaline) indicate a granitic source rock, probably Laurentian basement. The thinly laminated nature of the protolith probably indicates relatively calm water lacking high turbidity; but moderate energy, including possibly mild wave and/or tidal action, was required for currents to move the sand body out onto the shelf and to produce the cross laminations. Although the trilobite fossils are marine, their eurytopic nature sheds little light on the depositional environment of the unit. It grades laterally into thinly laminated marbles and its position within these upper Shelvin Rock Church marbles indicates that it was probably deposited landward of the carbonate platform rim or ramp. Thus, it must have been a sand lens deposited on the carbonate platform in roughly the same overall setting as the thinly laminated micrite, and a shallow-marine origin is therefore likely. Such sandstone bodies, found in association with carbonate sequences with little or no associated shale, were common within the extensive carbonate platforms of the middle to late Precambrian and early Paleozoic (Pettijohn and others, 1987), although they are generally much less feldspathic than the Averett Branch Member. Because of the lack of interbedded shale and carbonate, most are classified as shallow-marine deposits. The Averett Branch Metaarkose appears analogous to these deposits in terms of lithology and carbonate association. Similar carbonate-associated sandstones are rare in modern carbonate settings, presumably because the platforms are not as extensive as those formed during the Precambrian and Paleozoic (Pettijohn and others, 1987).

Gooch Branch Chert

Description

The Gooch Branch Chert (Figures 3 and 4C) is characterized by large blocks and narrow ridges of metachert cropping out above the relatively flat floor of the Sylacauga valley. Metachert within the 250 m to 600 m thick unit is white to cream in color and forms massive, moderately foliated lenses. Unfortunately, other lithologies within the unit are generally not well exposed. The metachert is likely a replacement of a primary carbonate (dolomitic) protolith. Locally exposed within the upper part of the metachert interval is a dull gray-white massive dolomitic marble as much as 70 m thick. Near the top, this marble contains abundant (> 90%) spherical to sub-spherical coated grains best classified as oöids/pisoids forming a packstone or pisolite in beds 2-3 cm thick, vaguely sorted by diameter (Figure 9A and B). In this context, the terms "oöid" (<2 mm diameter) and mud. This unit may represent a deeper-water outer ramp marlstone facies.

Gantts Quarry Formation

DESCRIPTION

Capping the Gooch Branch Chert is the uppermost unit of the Sylacauga Marble Group, the Gantts Quarry Formation, which is exposed in the core of the Sylacauga syncline (Figure 3). The Gantts Quarry Formation, composed of a relatively pure, fine- to medium-grained, calcitic marble, is the most intensely quarried marble in the Sylacauga Marble Group, being prized for dimension and decorative stone, filler, and other industrial uses. Essentially all exposures of the unit are within marble quarries. The top of the unit is defined by the pre-Lay Dam Formation unconformity. The marble is dominantly white, but localized layers of off-white, light gray, dark gray, and pink marble can be found. Thin dark gray phyllite laminations (< 1 cm thick) composing less than 5 percent of the rock are present in all exposures of the unit. The unit also contains intervals a few meters to several meters thick of dark gray, dolomitic marble layers that were mechanically more competent than the calcite marble during synmetamorphic deformation, and these beds are commonly highly boudinaged.

Paleontology

The high calcite content of the unit results in the fact that synmetamorphic ductile deformation is much more strongly partitioned into the Gantts Quarry Formation than other (mostly dolomitic) units of the Sylacauga Marble Group. Outcrop-scale isoclinal and sheath folds are common. Extensive deformation and metamorphic recrystallization have obliterated essentially all primary features other than bedding. Three conodont species, however, *Scolopodus gacilis, Gloptoconus qaudraplicatus,* and *Eucharodus parallelus* (Figure 10), were recovered from quarries and outcrops near Carara (Figure 2) from within an interval 60 to 70 m from the base of the unit (Tull and others, 1988) (Figure 4C). These are of latest Early Ordovician age (Arenig) (North American Midcontinent Faunas D-E) and are representative of warm, shallow-water biofacies (Tull and others, 1988).

Interpreted Depositional Environment

Although there are almost no primary features that allow for speculation about the depositional environment, the homogeneous, fine-grained nature and high purity of the dominantly "cream" white marble, suggest that the protolith was a micrite, and the included conodonts indicate a shallow, tropical environment.

Stratigraphic and Depositional Environment Summary

Protoliths of the Sylacauga Marble Group were dominantly peritidal carbonate sediments. Other than possible storm deposits, most of the carbonate units were apparently deposited upon a carbonate shelf under very calm, non-turbid conditions, landward of the platform rim or ramp. Minor parts of the marble sequence, like the upper Gooch Branch Chert, may represent inner or shallow ramp facies. The Fayetteville Phyllite is the only basin-wide siliciclastic unit within the Sylacauga Marble Group. It resulted from a regressive event in which terrigenous clastic sediment prograded out onto the carbonate platform. A subsequent transgression reestablished carbonate deposition. The lower Shelvin Rock Church Formation probably represents a localized depression or intrashelf depocenter on the carbonate platform in which a mix of shale and carbonate sediment was deposited. Carbonate breccia found in palinspastically more outboard exposures of the lower Jumbo Dolomite are the only deposits indicative of possible deeper water, outer ramp or off rim deposits. Unfortunately, sparsity of exposures with which to document lateral facies variations, rarity of paleontological materials, and obliteration of carbonate microstructures by deformation and metamorphic recrystallization, preclude development of a more rigorous depositional model for the marble sequence.

zation has apparently precluded preservation of microstructures within the cortex, thus preventing recognition of internal fabrics other than the faint concentric laminations.

Along strike 750 m east of the pisolitic packstone marble, charcoal-gray dolomitic marble occurs in a similar stratigraphic position. Both lithologies are overlain by the same maroon phyllite (see below), and it is likely that the two lithologies grade laterally into one another. The dark dolomitic marble consists of 4-7 mm thick dolomitic micrite beds interbedded with beds 1-2 cm thick composed predominantly (90-95%) of small, angular carbonate fragments (long dimensions of 0.1-0.9 mm) that appear to be intraclasts. Between the individual fragments (intraclasts?) and within the fine-grained layers, small spherical structures less than 1 mm in diameter appear to be oöids, containing a core and concentric laminations. Like the lithology containing the oöids/pisoids, the dark dolomitic marble also contains siltstone clasts (0.3 mm in diameter). Overlying the pisoid and oöid (?)/intraclast-bearing dolostone is a 20-30 m thick, dull, earthy tan to maroon phyllite that marks the boundary between the Gooch Branch Chert and overlying Gantts Quarry Formation throughout most of the study area. The highly porous nature of the phyllite suggests that it was calcareous before weathering, and thus the protolith is believed to have been a calcareous mudstone or marl.

Interpreted Depositional Environments

Although little can be inferred about the depositional environment of the protolith of the metachert, the other lithologies within the Gooch Branch Chert provide some basis for interpretation. The oöid/pisoid and oöid/intraclast facies apparently grade laterally into one another. Pisoids and oöids form in a variety of environments but are common components of shelf-margin sands (Tucker and Wright, 1990). The bedded and sorted nature of the oölitic/pisolitic packstone suggests that the rock may have accumulated as a near-shoreline carbonate body in a setting such as an oölitic/pisolitic shoal complex or offshore bar. A shallow-marine (inner, shallow ramp?) origin is also supported by the presence of intraclasts within these rocks. Peloids, which dominate the oöid/pisoid nuclei, in addition to the skeletal fragment nucleii, could have been derived from nearby algal mats on the adjacent platform interior, as algae were important producers of peloids in the early to middle Paleozoic (Tucker and Wright, 1990). Peloids commonly make up an important constituent of the sand fraction of low energy shallow marine carbonate sediments. The other nuclei (sand, silt, and lithic fragments) could have been easily transported from subaerial exposures on the platform by wind, particularly in an arid setting. No cross beds, ripples, or channels have been observed in association with the oölitic/pisolitic packstone.

The intraclastic dolostone resembles a series of storm deposits. The alternation of the intraclastic layers with the fine-grained micritic/oölitic layers is indicative of episodic storms, in which the thicker intraclast beds probably represent rapidly formed, turbulent storm deposits. The thinner interbedded fine-grained beds probably represent longer, quiet periods of deposition when the shallow-marine waters were calm (Scholle and others, 1983). Many of the intraclasts are of biologic origin, and include possible oncoids derived from algal mats that grew on the tidal-flat. Low tide stands would have exposed these mats to desiccation. Once desiccated, the mats could easily be ripped up by storms to form intraclasts. The intraclasts that do not have an obvious biologic origin may have been supplied from the supratidal zone. A calcite matrix surrounds many of the dolomitic intraclasts. It is thus possible that dolomitization of these intraclasts is primary and that they originated as dolomitic crusts in the supratidal zone. If the climate were arid, then a sabkha-type facies could generate dolomitic crusts. A supratidal dolomitic crust would desiccate and eventually break up to produce numerous intraclasts during storm events (Tucker and Wright, 1990). The laterally extensive calcareous phyllite overlying the pisoid/oöid/intraclast dolostone is distinctive because it originally contained an appreciable amount of siliciclastic

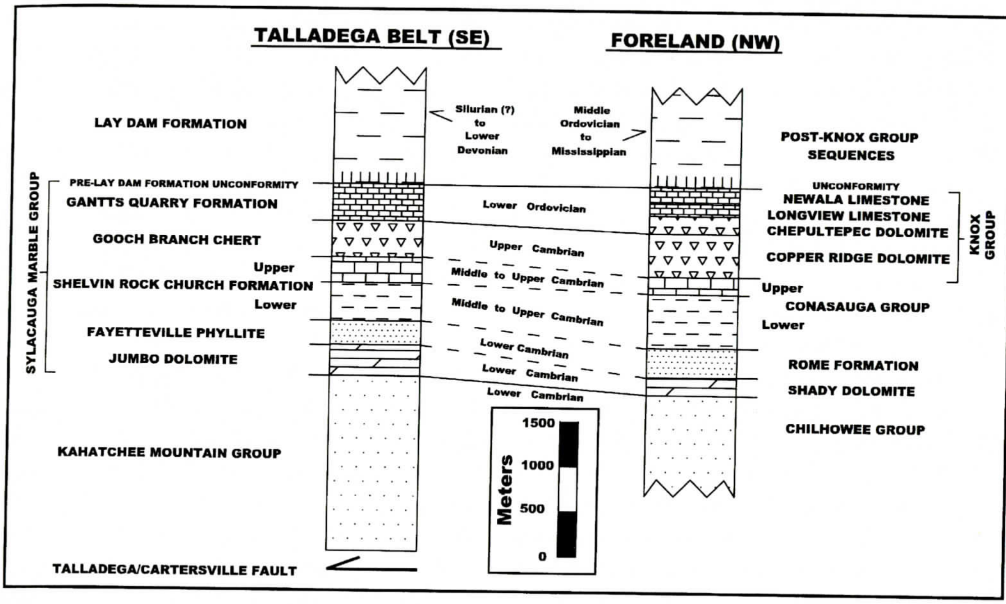


Figure 11. Proposed correlation of Sylacauga Marble Group with Appalachian foreland Cambrian-Lower Ordovician stratigraphy (Alabama foreland average thicknesses are used here).

bank sedimentation during post-rift, passive-margin subsidence and transgression established during deposition of the Chilhowee Group following Iapetus rifting and initial drifting. It is dominated by medium- to thick-bedded, light- to dark gray, medium- to fine-grained dolostone, but surface exposures are usually represented by massive, yellowish orange chert within a carbonate residuum. The most compelling evidence that the Shady Dolomite and Jumbo Dolomite are correlative is the fossil evidence (Tull and others, 1988). Early Cambrian archaeocyathids from the Jumbo Dolomite link it to the Shady Dolomite temporally and environmentally (Palmer and Rozanov, 1976; Bearce and McKinney, 1977; Pfeil and Read, 1980; Tull and others, 1988). Archaeocyathids of classes *Regulares* and *Irregulares*, order *Ajacicyathida,* found in the Jumbo (Figure 6) also are known in the Shady Dolomite immediately north of outcrops of the Sylacauga Marble Group in the Sleeping Giants range near Talladega, 16 km northeast of Winterboro (Figures 1 and 2) (Bearce and McKinney, 1977); thus they provide direct biostratigraphic correlation between the two units. Both units are dominantly dolostone, and contain zones of massive chert. Other lithologic similarities exist as well. Like the Jumbo, the Shady Dolomite contains a significant amount of quartz silt and sand within laminated and massive dolostone layers near the base (Bearce, 1985). Similar quartz-rich Shady dolostones have been described in Virginia by Pfeil and Read (1980). Many of the quartz silt and sand-rich layers are interbedded with thin algal laminations.

The most definitive primary features in the Jumbo Dolomite, including possible algal "clumps" or nodular evaporites, dessication cracks or gas escape structures, tepee structures, fenestrae, oncoids, and archaeocyathids, indicate an intertidal to shallow-marine origin for most of the unit. In Virginia, Pfeil and Read (1980) described two members of the Shady Dolomite that are lithologically similar to the shallow-marine facies of the Jumbo Dolomite. The Austinville Member is a stromatolitic and massive dolostone with minor quartzose grainstones, containing archeocyathids and oncalite layers (Pfeil and Read, 1980). Much of this member has been interpreted to be intertidal on the basis of desiccation cracks and tepee structures. The desiccation features found in the cryptalgal laminated facies are similar to those

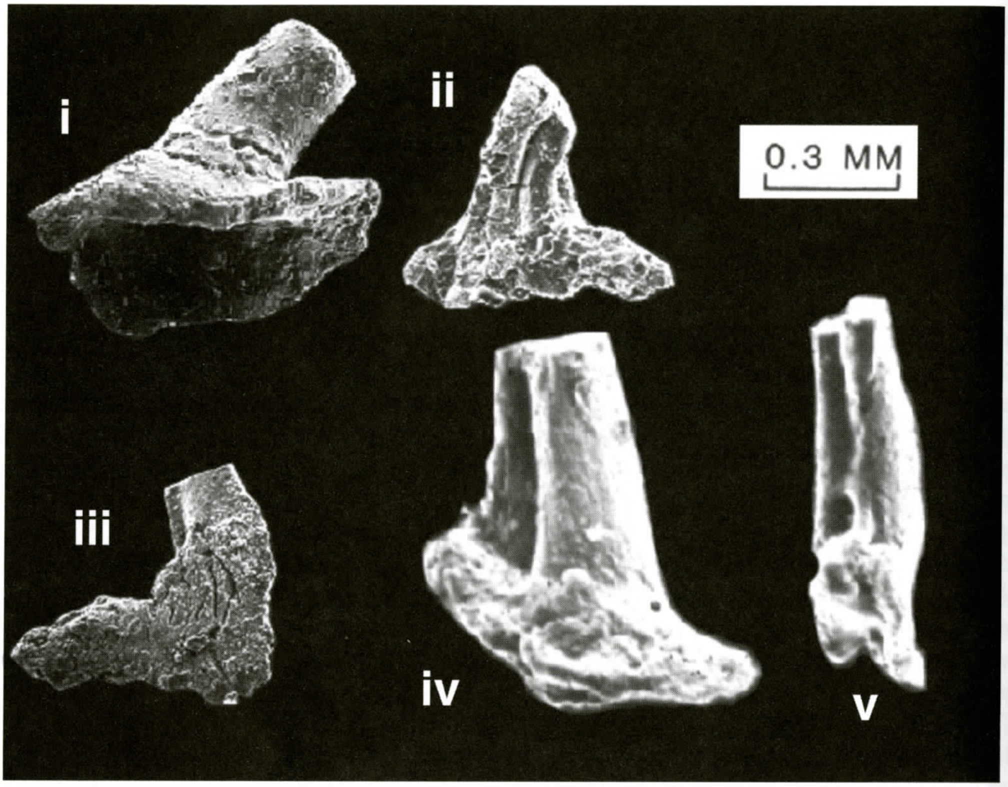


Figure 10. SEM photographs of Early Ordovician conodonts from the Gantts Quarry Formation. i) *Eucharodus parallelus* (Branson and Mehl); ii) *Glyptoconus quadraplicatus* (Branson and Mehl); iii) *Paroistodus sp.*; iv) and v) Sclolopodus gracilis (Ethington and Clark). Modified from Tull and others, 1988.

CORRELATION OF THE SYLACAUGA MARBLE GROUP WITH THE CAMBRIAN-ORDOVICIAN CARBONATE SEQUENCE OF THE APPALACHIAN FORELAND

Introduction

The palinspastic distance between exposures of the Sylacauga Marble Group and the immediately adjacent Cambrian-Ordovician carbonate sequence of the Appalachian thrust belt to the northwest was a minimum of many tens of kilometers on the basis of the presence of the large Kelley Mountain half window (Figure 2) and metamorphic grade differences. Important similarities in age, lithology, lithologic sequence, and depositional setting, however, do exist between the marble sequence and the foreland carbonate units. These provide strong support for correlating the two sequences and thus establishing the Sylacauga Marble Group as a more outboard part of the Cambrian-Ordovician carbonate platform that was subsequently detached and thrust above more inboard parts of this platform. As such, it is the most distally preserved part of the platform sequence. In the following section we summarize this comparison (Figure 11).

Jumbo Dolomite/Shady Dolomite

In the Appalachian thrust belt in Alabama the Lower Cambrian Shady Dolomite, estimated to be as much as 190 m thick (Thomas, 1982), lies between the underlying Chilhowee Group and the overlying Rome Formation. The Shady Dolomite represents the initiation of carbonatecally open to marine currents (Thomas and others, 2000). Restricted circulation, in combination with an arid climate resulted in Rome evaporite and associated facies (Thomas and others, 2000). A similar lithofacies distribution pattern is suggested by the Fayetteville Phyllite, in which phyllites grade laterally into marble and metasandstone.

Shelvin Rock Church Formation/ Conasauga Formation (Group)

The Shelvin Rock Church and Conasauga Formations (the Conasauga has "formation" status in Alabama and "group" status in Tennessee) are lithologically similar and contain a common Middle Cambrian fauna. The Shelvin Rock Church Formation ranges between ~350 m and ~1000 m in thickness. The thickest interval of the Conasauga Formation in Alabama is comparable at ~930 m, but the thickness range is also highly variable, and at some localities the interval is only ~100 m thick (Osborne and others, 2000). The Conasauga ranges from Middle to Late Cambrian in age, and represents the transition from the regressive Rome clastic succession to the more massive carbonate facies of the Upper Cambrian to Lower Ordovician Knox Group. Osborne and others (2000) described the unit in Alabama as a complex interval relative to thickness, lithofacies, diagenesis, and nomenclature. The highly variable mix of lithologies consists predominantly of limestone, dolostone, and shale in varying proportions, with minor sandstone. Variable degrees of dolomitization and silicification have complicated correlation and nomenclature. In addition, the unit commonly changes character significantly from one thrust sheet to another within the Appalachian foreland (Osborne and others, 2000).

The interbedded marbles and phyllites (limestones and shales) within the lower Shelvin Rock Church Formation are a common characteristic of the lower Conasauga interval in many parts of the foreland in Alabama (Thomas and others, 2000) as well as Tennessee and Virginia (Hasson and Haase, 1988; Markello and Read, 1982). One feature common to the Conasauga but not recognized in the Shelvin Rock Church is the presence of oölitic intervals. Additionally, some dolomitic intervals in the Conasauga are chertified, but metachert does not appear in the Shelvin Rock Church.

As an explanation of why deeper water clastic and carbonate rocks grade laterally into shallow-water carbonate rocks, both Markello and Read (1982) and Hasson and Haase (1988) interpreted the lower Conasauga (characterized by interbedded limestones and shales) as having been deposited within intrashelf depocenters, thus accounting for the abrupt thickening and thinning within the unit. Thomas and others (2000) suggested that the irregular distribution of Conasauga carbonate and coeval fine siliciclastic rocks resulted from significant variations in depositional setting and sediment source due to syndepositional faulting. They attributed this faulting to crustal instability associated with continued (through Middle Cambrian time) migration of the Ouachita rift along the transform bounding the southern margin of the Alabama continental promontory. The Conasauga intrashelf depocenters may thus represent regions of the platform that underwent more significant subsidence as a result of syndepositional fault motion. Differential subsidence of fault blocks beneath the platform would account for the abrupt thickening and thinning and the complex assemblage of sedimentary facies within the Conasauga interval. Apparently, many of these fault blocks were tilted, because significant variations in Conasauga thickness occur within the same foreland thrust sheet (Thomas and others, 2000). The same is true of the Shelvin Rock Church Formation in the Talladega belt (Figure 7).

The depositional setting of the lower Shelvin Rock Church Formation conforms well to an intrashelf depocenter model of Conasauga deposition and suggests that syndepositional basement faults may have been dispersed at least as far outboard on the southeast trailing margin of the Alabama promontory as the region now represented by the Talladega belt, i.e. very near the shelf edge. The presence of a cyclic siliciclastic/carbonate intrashelf depocenter in the Talladega belt indicates that the siliciclaswithin the Jumbo. The cryptalgal laminites of the Shady were deposited upon low-energy tidal-flats (Pfeil and Read, 1980). The other lithologically similar facies of the Shady is the Ivanhoe Member. It is mainly a stromatolitic dolostone, but also contains shale layers (Pfeil and Read, 1980) not found in the intertidal to shallow-marine facies of the Jumbo.

The carbonate breccia from the most outboard (southeast) part of the Jumbo (Pendexter, 1982) bears a striking resemblance to a lithology from the Shady described by Pfeil and Read (1980). This lithology likely originated as a slope-debris flow in which the intraclasts were fragments derived from the edge of the shallow-water carbonate platform that moved via debris flows across the shelf break and part of the way down the slope of the bank. Thus, this lithology may represent an off-shelf slope facies. With corroborating evidence (known shelf edge facies), Pfeil and Read (1980) identified a lithology within the Patersonville Member of the Shady Dolomite that is known to be a slope facies. This lithology, described as an oligomictic breccia, is almost identical to the carbonate breccia facies described by Pendexter (1982) from the Jumbo Dolomite near Jumbo. Pfeil and Read (1980) interpreted this facies to be a slope debris flow that had migrated a relatively short distance down the slope, thus explaining why it is not as well sorted as a turbidite.

Fayetteville Phyllite/Rome Formation

In the Appalachian foreland the passive margin transgressive carbonate facies of the Shady Dolomite was abruptly interrupted by an influx of craton-derived clastic sediment forming the Rome Formation of Early Cambrian age. Thomas and others (2000) suggested that this clastic influx was genetically associated with a small component of crustal extension and uplift in the present Appalachian foreland during the initiation of the Ouachita rift that propagated eastward along a transform fault (Alabama-Oklahoma transform) at the southern margin of the Alabama continental promontory at this time. The Rome consists of a heterogeneous sequence of variably colored mudstones, siltstones, and rare very fine-grained sandstones containing interbedded limestone and dolostone. In the subsurface the unit contains anhydrite and other features of evaporite deposition (Thomas and others, 2000).

The Fayetteville Phyllite, which contains many similar lithologies and shares a similar depositional setting with the Rome Formation, also marks a regression during which siliciclastic sediments (shale and arkose) prograded out onto the carbonate platform in a shallow-marine environment. Other than a difference in degree of metamorphism, the maroon and charcoal-purple phyllites of the Fayetteville are essentially identical to typical shales of the Rome Formation in Alabama. Fayetteville microbreccias, interpreted to have formed in a shallow-water/intertidal zone, in which the breccia fragments either were derived as storm-generated rip-up clasts or desiccation-generated cracks, also have similar analogues in the Rome. Although no fossils have been recovered from the Fayetteville Phyllite, it can be bracketed between Early and Middle Cambrian by archaeocyathids from the underlying Jumbo Dolomite and trilobites from the overlying Shelvin Rock Church Formation, thus conforming to the age of the Rome Formation. Correlation of the Rome Formation and Fayetteville Phyllite indicates that the influx of craton-derived clastic sediments prograded out across the platform at least as far as the palinspastic position of the Talladega belt and a significant component of these sediments was arkosic sand.

Synchronous deposition of carbonate and siliciclastic sediments, with lateral facies changes from quartzofeldspathic sand, or mud, to carbonate sediments are also common in the Rome Formation. Typically, siliciclastic and carbonate sediments are not synchronously deposited within the same basin. McReynolds and Driese (1994) developed a depositional model for the Rome that may explain this pattern. In their model, the deposition of the various lithofacies is heavily influenced by the geometry of the underlying Shady Dolomite, a geometry that may have been affected by syndepositional faulting, forming basins that were near sea level and lo-

Gantts Quarry Formation/Upper Knox Group (Newala/Longview Limestone)

The upper Knox Group is distinguished from units below it by the relative rarity of both chert and dolostone layers. Beds of Newala Limestone are commonly massive and consist of high-calcium, pearly white to light gray micritic limestone with some dolomite (Gore and Whitfield, 1974), analogous to the "cream" calcite marbles of the Gantts Quarry Formation. Within the Newala are thick beds of fossiliferous, fine-grained packstone, wackestone, and mudstone. The Gantts Quarry Formation, however, is essentially devoid of primary features, but the unit has yielded the same uppermost Early Ordovician (Arenigian) conodont species (Figure 10) as those found in the Newala, indicating a warm, shallow-marine environment and equivalency in age (Tull and others, 1988).

CONCLUSIONS

Some units of the Sylacauga Marble Group have been thought to be correlative with parts of the Cambrian-Ordovician Appalachian carbonate platform since Prouty (1916) first conducted work on the "Sylacauga marble member." The evidence presented herein supports and strengthens this basic correlation and suggests that the marbles represent the most distally preserved segment of that platform, having formed near the outer shelf margin. Preserved primary structures found throughout much of the Sylacauga Marble Group indicate that carbonate peritidal environments persisted during most of the group's depositional history, implying that intratidal to shallow-marine growth of this outer part of the carbonate platform lasted, at least intermittently, for some 80 m.y. Close lithostratigraphic correlation with the Cambrian-Ordovician carbonate sequence in Appalachian foreland, as well as similar unit thicknesses (Figure 11), indicate that a generally consistent depositional setting and platform architecture extended across the Alabama promontory from the more inboard parts of the platform to the very near shelf edge Sylacauga Marble Group. If the Alabama promontory formed as an upper plate (distal) extensional margin (Thomas, 1993), then the margin would have undergone minimal lithospheric thinning and developed only a narrow continental slope (Warnicke and Tilke, 1989), allowing the shallow carbonate platform sequence to extend nearly to the transition between continental and oceanic crust. The palinspastic width of this carbonate platform was well in excess of 200 km across the continental projection represented by the Alabama promontory (Thomas and others, 2000).

The only significant depositional change to affect the entire Sylacauga Marble Group is marked by deposition of the Lower Cambrian (?) Fayetteville Phyllite (Rome Formation equivalent), which represents a regression that resulted in the progradation of siliclasitic sediments out across essentially the entire carbonate bank, at least as far as the distal part represented by the Talladega belt. Fine siliciclasitic sediments continued to be channeled across the platform via a dispersal system that funneled mud and silt into a Middle to Upper (?) Cambrian Shelvin Rock Church Formation intrashelf basin. Sea level rise subsequently reestablished peritidal carbonate deposition.

In summary, the Sylacauga Marble Group is an Early Cambrian to Early Ordovician carbonate platform sequence that was deposited dominantly in a peritidal environment near the outer shelf margin of Laurentia along the Alabama promontory. It represents the lithologic, depositional, and paleontologic southeastward extension of the foreland carbonate platform sequence of equivalent age.

ACKNOWLEDGMENTS

Support for this project was from Amoco Production Company and the National Cooperative Geologic Mapping Program EDMAP Component. William Parker and Neil Lundberg provided advice and guidance during much of the project. Anita Harris gave helpful guidance concerning the search for paleontological materials and she and John Repetski analyzed conodont samples. Ken McKinney analyzed archaeocyathids and David R. Schwimmer free-

tic dispersal system(s) extended to the outermost parts of the platform. Proposed intrashelf depocenters in the Conasauga are, however, much larger than that within the lower Shelvin Rock Church Formation (several tens of kilometers across vs. ~10 km across) (Markello and Read, 1982). The intrashelf depocenter represented by the lower Shelvin Rock Church Formation may appear deceptively small in areal extent because only a two-dimensional (map) view can be obtained. Alternatively, the size of the proposed Shelvin Rock Church intrashelf depocenter may be the result of a smaller region of subsidence due to block faulting along outer parts of the platform.

The upper Shelvin Rock Church Formation consists mostly of thinly laminated and banded, coarsely crystalline marble with a thick lens of metaarkose (Averett Branch Member). The thinly laminated marbles interlayered with thicker layers of what were probably grainstones and/or packstones suggest an association with peritidal carbonate deposits (Tucker and Wright, 1990). Like the Shelvin Rock Church Formation, in many sections in the Appalachian foreland the Conasauga interval grades upward from interbedded carbonates and shales into carbonate-dominanted successions. This transition represents reestablishment of a passive margin shelf and tectonic stabilization following the synsedimentary faulting associated with migration of the Ouachita rift segment outboard of the Alabama continental promontory (Thomas and others, 2000). The Averett Branch metaarkose is an anomalous, spatially restricted, sand lens within the upper Shelvin Rock Church Formation. Similar sandstones are rare in the Conasauga interval of the foreland, where they are much thinner and associated predominantly with shale (Osborne and others, 2000). Middle Cambrian fossils found within the Averett Branch, however, provide a solid biostratigraphic link between the Shelvin Rock Church Formation and the Conasauga interval. The origin of the Averett Branch is an enigma; it may have been derived from uplift of local basement horsts near the outer platform margin.

Gooch Branch Chert/lower Knox Group (Copper Ridge-Chepultepec Dolomite)

Like the Gooch Branch Chert, the lower Knox Group (Copper Ridge/Chepultepec Dolomite) commonly forms ridges of white or light gray, dense chert (Brockman, 1978). Although silicified *Cryptozoans* occur in the Copper Ridge Dolomite, primary features have not been found in the metachert facies of the Gooch Branch Chert. A rarity of carbonate outcrops is a common attribute to both units, but where carbonate rocks are exposed, they are dominantly dolomitic. The Gooch Branch Chert consists of light colored calcitic to dolomitic marble and very dark, charcoal gray dolomitic marble with white calcite banding and/or cement. Similar lithologies have also been recognized in the Copper Ridge Dolomite in Alabama (Sternbach, 1984). The lighter calcitic/dolomitic marble in the Gooch Branch Chert contains oölitic/pisolitic beds near the top of the unit. Oölitic lenses are also common in the Copper Ridge Dolomite (Sternbach, 1984).

The lower Knox Group in Alabama likely formed in an intertidal to supratidal environment marked by widespread syngenetic desiccation and mudcrack formation on a dry hypersaline carbonate shoreline (Sternbach, 1984). Sternbach (1984) interpreted parts of the unit to have formed as arid sabkha flats. The Gooch Branch likely represents a more distal portion of the lower Knox Group; the upper part of the unit possibly represents facies associated with an upper (shallow) carbonate ramp. Importantly, the generally poor exposure of both units prevents a significantly detailed comparison.

Paleontological evidence from the underlying Shelvin Rock Church Formation (Middle Cambrian) and the overlying Gantts Quarry Formation (Lower Ordovician) allows a possible Late Cambrian age for the Gooch Branch Chert, compatible with that of the Copper Ridge Dolomite.

Pfeil, R. W., and Read, J. F., 1980, Cambrian carbonate platform facies, Shady Dolomite, southwestern Virginia, U. S. A.: Journal of Sedimentary Petrology, v. 50, p. 91-116.

Prouty, W. F., 1916, Preliminary report on the crystalline and other marbles of Alabama, Geological Survey of Alabama Bulletin 18, 49 p.

Rankin, D. W., Drake, A. A., Jr., Glover, L., III, Goldsmith, R., Hall, L. M., Murray, D. P., Ratcliff, N. M., Read, J. F., Secor, D. T., Jr., and Stanley, R. S., 1989, Pre-orogenic terranes, *in* Hatcher, R. D., Jr., Thomas, W. A., and Viele, G. W., eds., The Appalachian-Ouachita orogen in the United States: Boulder, Colorado, Geological Society of America, The Geology of North America, F-2, p. 7-100.

Read, J. F., and Pfeil, R. W., 1983, Fabrics of allochthonous reefal blocks, Shady Dolomite (Lower to Middle Cambrian), Virginia Appalachians: Journal of Sedimentary Petrology, v. 53, p. 761-778.

Rodgers, J, and Shaw, C. E., 1962, Age of the Talladega Slate of Alabama: Geological Society of America Special Paper 73, p. 226-227.

Schlager, Wolfgang, 1992, Sedimentology and sequence stratigraphy of reefs and carbonate platforms: American Association of Petroleum Geologists Continuing Education Short Course Note Series No. 32, 71 p.

Scholle, P. A., Bebout, D. G., and Moore, C. H., eds., 1983, Carbonate depositional environments: American Association of Petroleum Geologists Memoir 33, 708 p.

Schwimmer, D. R., 1989, Taxonomy and biostratigraphic significance of some Middle Cambrian trilobites from the Conasauga Formation in western Georgia: Journal of Paleontology, v. 63, p. 484-494.

Shaw, C. E., 1970, Age and stratigraphic significance of the Talladega Slate: evidence of pre-Middle Ordovician tectonism in central Alabama: Southeastern Geology, v. 11, p. 253-267.

Simpson, E. L., and Eriksson, K. A., 1989, Sedimentology of the Unicoi Formation in southern and central Virginia: Evidence for late Proterozoic to Early Cambrian rift-to-passive margin transition: Geological Society of America Bulletin, v. 101, p. 42-54.

Smith, F. E., 1888, Report of progress for the years 1884-1888: Alabama Geological Survey Report of Progress, 24 p.

Sternbach, L. R., 1984, Carbonate facies and diagenesis of the Cambrian-Ordovician shelf and slope-margin (the Knox Group and Conasauga Formation), Appalachian fold belt, Alabama [M. S. thesis]: Troy, New York, Rensselaer Polytechnic Institute, 165 p.

Thomas, W. A., 1982, Stratigraphy and structure of the Appalachian fold and thrust belt in Alabama, *in* Thomas, W. A., and Nearthery, T. L., eds., Appalachian Thrust Belt in Alabama: Tectonics and Sedimentation, Geological Society of America, New Orleans, Louisiana, Guidebook for Field Trip No. 13, p. 55-60.

Thomas, W. A., 1993, Low-angle geometry of the late Precambrian-Cambrian Appalachian-Ouachita rifted margin of southeastern North America: Geology, v. 21, p. 921-924.

Thomas, W. A., Astini, R. A., and Osborne, W. E., 2000, Tectonic framework of deposition of the Conasauga Formation: Alabama Geological Society 37th Annual Field Trip Guidebook, p. 19-40.

Tucker, M. E., and Wright, V. P., 1990, Carbonate Sedimentology: Oxford, Blackwells, 482 p.

Tull, J. F., 1982, Stratigraphic framework of the Talladega slate belt, Alabama Appalachians, *in* Bearce, D.N., Black, W.W., Kish, S., and Tull, J.F., eds., Tectonic studies in the Talladega and Carolina slate belts, southern Appalachian orogen: Geological Society of America Special Paper 191, p. 3-18.

Tull, J. F., 1985, Stratigraphy of the Sylacauga Marble Group, *in* Tull, J. F., Bearce, D. N., and Guthrie, G. M., eds., Early evolution of the Appalachian Miogeocline: upper Precambrian-lower Paleozoic Stratigraphy of the Talladega Slate Belt: Alabama Geological Society 22nd Annual Field Trip Guidebook, p. 21-26.

Tull, J. F., 1995, Hollins Line transpressional duplex: eastern-western Blue Ridge terrane boundary: Geological Society of America Abstracts with Programs, v. 27, no. 2, p. 93.

Tull, J. F., 1998, Analysis of a regional middle Paleozoic unconformity along the distal southeastern Laurentian margin, southernmost Appalachians: implications for tectonic evolution: Geological Society of America Bulletin, v. 110, p. 1149-1162.

Tull, J. F., Harris, A. G., Repetski, J. E., McKinney, F. K., Garrett, C. B., and Bearce, D. N., 1988, New paleontologic evidence constraining the age and paleotectonic setting of the Talladega slate belt, southern Appalachians: Geological Society of America Bulletin, v. 100, p. 1291-1299.

Tull, J. F., Ragland, P. C., and Durham, 1998, R. B., Geologic, geochemical, and tectonic setting of felsic metavolcanic rocks along the Alabama recess, southern Appalachian Blue Ridge: Southeastern Geology, v. 38, no. 1, p. 39-64.

Tull, J. F., and Telle, W. R., 1989, Tectonic setting of olistostromal units and associated rocks in the Talladega slate belt, Alabama Appalachians, *in* Horton, J.W., and Rast, N., eds., Melanges and olistostromes of the Appalachians: Geological Society of America Special Paper 228, p. 247-269.

Van der Voo, R., 1998, Paleozoic paleogeography of North America, Gondwana, and intervening displaced terranes: Comparisons of paleomagnetism with paleoclimatology and biogeographical patterns: Geological Society of America Bulletin, 100, 311-324.

Warnicke, B. and Tilke, P. G., 1989, Extensional Tectonic Framework of the U.S. Central Atlantic Passive Margin: in Extensional Tectonics and Stratigraphy of the North Atlantic Margins, Tankard, A. J., and Balkwill, eds.: American Association of Petroleum Geologists Memoir 46, p. 7-21.

Wilson, J. L., 1975, Carbonate facies in geologic history:

ly gave advice and opinions on the trilobite fauna. D. Joe Benson, Robert Hatcher, Jr., and Bill Thomas provided very helpful comments and perspective on the manuscript.

REFERENCES CITED

Astini, R. A., Thomas, W. A., and Osborne, W. E., 2000, Sedimentology of the Conasauga Formation and equivalent units, Appalachian thrust belt in Alabama: Alabama Geological Society 37th Annual Field Trip Guidebook, p. 41-71.

Bearce, D. N., 1985, Early Cambrian nappes bordering Talladega belt in eastern Alabama, *in* Tull, J. F., Bearce, D. N., and Guthrie, G. M., eds., Early evolution of the Appalachian Miogeocline: upper Precambrian-lower Paleozoic Stratigraphy of the Talladega Slate Belt: Alabama Geological Society 22nd Annual Field Trip Guidebook, p. 37-49.

Bearce, D. N., and McKinney, F. K., 1977, Archaeocyathids in eastern Alabama: Significance to geological interpretation of Coosa deformed belt: Geology, v. 5, p. 742-754.

Brockman, G. F., 1978, Pre-Pennsylvanian stratigraphy of the Birmingham area, Jefferson county, Alabama: Alabama Geological Society 16th Annual Field Trip, Guidebook, p. 1-4.

Bucher, K., and Frey, M., 1994, Petrogenesis of Metamorphic Rocks, New York, Springer-Verlag, 318 p.

Butts, C., 1926, The Paleozoic rocks, *in* Adams, G. L., and others, Geology of Alabama: Geological Survey of Alabama Special Report 14, p. 40-223.

Butts, C., 1940, Description of the Montevallo and Columbiana Quadrangles: U.S. Geological Survey Atlas, Folio, 226, p. 0-19.

Carozzi, A. V., 1989, Carbonate rock depositional models; a microfacies approach: Prentice-Hall, Englewood Cliffs, New Jersey, 604 p.

Elliott, T., 1986, Siliciclastic shorelines, *in* Reading, H. G., ed. Sedimentary Environments and facies, Oxford, England, Blackwell Scientific Pub., p. 155-188.

Gastaldo, R. A., Guthrie, G. M., and Steltenpohl, M. G., 1993, Mississippian fossils from southern Appalachian metamorphic rocks and their implications for late Paleozoic tectonic evolution: Science, v. 262, p. 732.

Gore, C. E., and Whitfield, J. W., 1974, Geology of a portion of the Gaston Steam Plant, *in* Thomas, W. A., and Drahovzal, J. A., eds., The Coosa Deformed Belt in the Alabama Appalachians: Alabama Geological Society 12th Annual Field Trip, Guidebook, p. 82-83.

Hardie, L. A., and Ginsburg, R. N., 1977, Layering: the origin and environmental significance of lamination and thin bedding, *in* Hardie, L. A., ed., Sedimentation on the modern carbonate tidal flats of northwest Andros Island, Bahamas: Baltimore, Johns Hopkins University Press, Studies in Geology, v. 22, p. 50-123.

Hasson, K. O., and Haase, C. S., 1988, Lithofacies and paleogeography of the Conasauga Group, (Middle and Late Cambrian) in the Valley and Ridge province of east Tennessee: Geological Society of America Bulletin, v. 100, p. 234-246.

Hatcher, R. D., Jr., 1989, Tectonic synthesis of the U. S. Appalachians: *in* Hatcher, R. D., Jr., Thomas, W. A., and Viele, G. W., eds., The Appalachian-Ouachita Orogen in the United States: Boulder, Colorado, Geological Society of America, The Geology of North America, F-2, p. 7-100. p. 511-535.

Horton, J. W., Jr., Drake, A. A., Jr., Rankin, D. W., and Dallmeyer, R. D.,1991, Preliminary tectonostratigraphic terrane map of the central and southern Appalachians: U.S. Geological Survey Miscellaneous Investigation Series, Map I 2163.

Johnson, J. H., 1961, Limestone building algae and algal limestones: Colorado School of Mines, Boulder, CO, Johnson Publishing Company, 297 p.

Johnson, L. W., 1999, The stratigraphy of the Sylacauga Marble Group and its correlation to the Cambrian-Ordovician carbonate rocks of the Appalachian foreland fold-and-thrust belt, Alabama Appalachians [M. S. Thesis]: Tallahassee, Florida, Florida State University, 127 p.

Leeder, M. R, 1982, Sedimentology: Herts, England, George Allen and Unwin Ltd,, 344 p.

Markello, J. R., and Read, J. F., 1982, Upper Cambrian intrashelf basin, Nolichucky Formation, southwest Virginia Appalachians: American Association of Petroleum Geologists Bulletin, v. 66, p. 860-878.

McCalley, H., 1897, Report on the valley regions of Alabama, Part II, the Coosa Valley Region: Alabama Geological Survey Special Report 9, 826 p.

McReynolds, J. A., and Driese, S. G., 1994, Paleoenvironments and facies relations of the Rome Formation (lower Cambrian) along Haw Ridge, Roane and Anderson counties, Tennessee: Southeastern Geology, v. 34, p. 1-24.

Miall, A. D., 1990, Principles of Sedimentary Basin Analysis, New York, NY, Springer-Verlag, p. 41-51.

Osborne, W. E., Thomas, W. A., Astini, R. A., and Irvin, G. D., 2000, Stratigraphy of the Conasauga Formation and equivalent units, Appalachian thrust belt in Alabama: Alabama Geological Society 37th Annual Field Trip Guidebook, p. 19-40.

Palmer, A. R. and Rozanov, A. Y., 1976, Archaeocytha from New Jersey: evidence for and intra-Cambrian unconformity in the north-central Appalachians: Geology, v. 4, p. 773-774.

Pendexter, W. S., 1982, Stratigraphic relationships of the carbonate sequence in the Talladega slate belt, Chilton and Coosa counties, Alabama: *in* Bearce, D.N., Black, W.W., Kish, S., and Tull, J.F., eds., Tectonic studies in the Talladega and Carolina slate belts, southern Appalachian orogen: Geological Society of America Special Paper 191, p. 61-68.

Pettijohn, F. J., Potter, P. E., and Siever, R., 1987, Sand and Sandstone: New York, NY, Springer-Verlag, p. 152-389.

SOUTHEASTERN GEOLOGY
V. 41, No. 2, July 2002, p. 103-117

THE PERSIMMON CREEK GNEISS, EASTERN BLUE RIDGE, NORTH CAROLINA-GEORGIA: EVIDENCE FOR THE MISSING TACONIC ARC?

SUSANNE MESCHTER MCDOWELL[1]

Department of Geology, Vanderbilt University, Nashville, TN 37235 (susannemeschter@hotmail.com)

CALVIN F. MILLER

Department of Geology, Vanderbilt University, Nashville, TN 37235 (millercf@ctrvax.vanderbilt.edu)

PAUL D. FULLAGAR

Department of Geological Sciences, University of North Carolina-Chapel Hill, Chapel Hill, NC 27599-3315

BRENDAN R. BREAM

Department of Geological Sciences, University of Tennessee, Knoxville, TN 37996-1410

RUSSELL W. MAPES[1]

Department of Geology, Vanderbilt University, Nashville, TN 37235

[1]Present address: Department of Geological Sciences, University of North Carolina-Chapel Hill, Chapel Hill, NC 27599-3315

ABSTRACT

The Persimmon Creek Gneiss (PCG) is a metamorphosed pluton in the Eastern Blue Ridge that ranges widely in composition, from gabbro to granodiorite, with tonalite dominating. Plagioclase (both magmatic and recrystallized) is by far the most abundant mineral. Quartz, biotite, and epidote are also ubiquitous, whereas potassium feldspar is sparse or absent and hornblende is present only in the most mafic rocks. The abundant sub- to euhedral epidote has euhedral zoning and is probably magmatic. Zircon ion probe U-Pb data indicate that the PCG crystallized 468 Ma and carried abundant inherited zircons, mostly of Grenville age.

In keeping with its obvious lithologic variability, the PCG ranges widely in major element composition (52-70 wt% SiO_2, ~1-3 wt% K_2O). It is depleted in high field strength elements and displays moderate LREE enrichment (~50-150 x chondrite), flat HREE at ~10 x chondrite, negative Eu anomalies, and moderate Sr concentrations (300-400 ppm). In all of these respects except HFSE depletion, it is unique among Ordovician plutons of the northern Georgia - South Carolina - North Carolina Blue Ridge and Inner Piedmont. Its Nd-Sr-O isotopic composition falls between those of mafic-ultramafic rocks and metasedimentary and basement rocks of the Blue Ridge and Inner Piedmont.

The geochemistry, mineral assemblages and textures, and field relations of the PCG suggest that it represents a deep-seated pluton that crystallized from a wet, oxidized magma. We propose that it formed as a result of subduction preceding Taconic collision of the Piedmont Terrane with Laurentia. It may be a rare remnant of a weakly developed, short-lived arc.

INTRODUCTION

The Eastern Blue Ridge and Inner Piedmont together comprise the Piedmont Terrane (Williams and Hatcher, 1983) or Piedmont Zone (Hibbard and Samson, 1995), which constitutes the core of the southern Appalachians. This region, located between undisputed Laurentian

Sringer-Verlag, New York, 471 p.
Winkler, G. F., 1976, Petrogenesis of metamorphic rocks: Sringer-Verlag, New York, 320 p.

at Pickens Nose, Bearpen Creek, and Bearpen Mountain in southern Macon County, North Carolina, and along Persimmon Creek in northwestern Rabun County, Georgia (Meschter, 2001; Hatcher, 1979).

METHODS

Fresh samples were collected from roadcuts and outcrops for thin sections, chemical analyses, and zircon separation. Standard mineral separation techniques were used to extract individual zircon grains from two of the samples, CPCMUL and PCHC. Zircons were handpicked and mounted in epoxy with standard AS57. Internal zoning of individual zircons was imaged by cathodoluminescence on an SEM at Stanford University; zoning images were then used as a guide for selection of analytical spots (cf. Miller and others, 2000). U-Pb analyses were performed at the University of California-Los Angeles using the Cameca IMS 1270 high-resolution ion microprobe. Both zircon rims and cores were analyzed with the primary beam focused to a ~20 micron spot. Analyses were corrected for common Pb using a ^{204}Pb correction, assuming common Pb ratios of $^{206}Pb/^{204}Pb = 17.98$, $^{207}Pb/^{204}Pb = 15.59$, and $^{208}Pb/^{204}Pb = 37.1$. All reported uncertainties in text and figures are $\pm 2\sigma$.

Minerals and textures were identified and described by standard optical microscopy. Zoning of epidote was visible in transmitted light and was further characterized using backscattered electron imaging (Hitachi S-4200 scanning electron microscope at Vanderbilt University).

Whole rock powders of fresh samples were used for major and trace element and O, Nd, and Sr isotopic analysis. Major and trace elements were analyzed by Activation Laboratories, Inc., using X-ray fluorescence, inductively coupled plasma mass spectrometry (ICP-MS), instrumental neutron activation analysis (INAA) and direct current plasma spectrometry. Silicate O isotope analyses were performed at Geochron Laboratories. Nd and Sr isotopic analyses were performed at the University of North Carolina-Chapel Hill on a multi-collector VG sector 54 mass spectrometer.

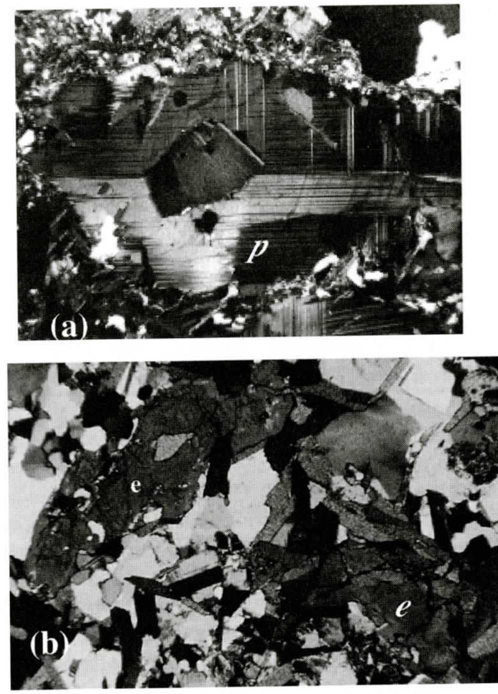


Figure 2. Photomicrographs of characteristic petrographic features of Persimmon Creek Gneiss. (a) Relict coarse, magmatic plagioclase [p] with modified grain boundary, surrounded by fine-grained, dynamically recrystallized quartz and feldspar. (b) Coarse, subhedral, zoned epidote [e].

FIELD AND PETROGRAPHIC CHARACTERISTICS

The PCG ranges in texture from weakly foliated and medium-coarse grained to finer grained and well foliated. The most prominent lithology is poorly foliated and characterized by abundant large, equant plagioclase grains set in a finer grained matrix, mostly of biotite and quartz. In the field and in thin section (Figure 2a) the plagioclase appears to be magmatic but recrystallized at its margins. Better foliated samples retain vestiges of magmatic texture in thin section but plagioclase and other minerals show strong evidence of recrystallization. There appears to be a continuum from magmatic to thoroughly recrystallized texture, which is supported by reconnaissance cathodoluminescence investigation of plagioclase. Multiple lu-

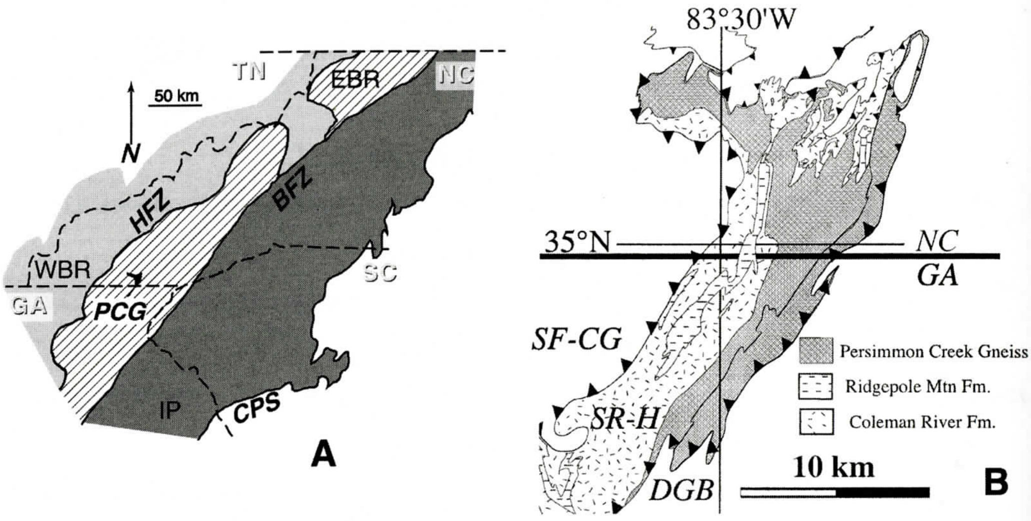


Figure 1. (a) Location of the Persimmon Creek Gneiss (PCG) with respect to major tectonic features (HFZ: Hayesville fault zone; BFZ: Brevard fault zone; CPS: Carolina-Piedmont suture; IP: Inner Piedmont; EBR: Eastern Blue Ridge; WBR: Western Blue Ridge. (IP + EBR = Piedmont Terrane) (b) Persimmon Creek Gneiss and its immediate surroundings, modified from Hatcher (1999). DGB: Dahlonega Gold Belt; SR-H: Soque River-Hayesville thrust sheet; SF-CG: Shope Fork-Chunky Gal thrust sheet.

crust and the exotic Carolina Terrane, remains an enigmatic aspect of Southern Appalachian crustal evolution. In the simplest models, it represents (a) the easternmost edge of Laurentia's passive margin; (b) an exotic terrane that was accreted to Laurentia via subduction during the Ordovician Taconic Orogeny (Williams and Hatcher, 1983; Shaw and Wasserburg, 1984; Horton and others, 1989); or (c) an original part of Laurentia that rifted away in Late Precambrian time but was subsequently reaccreted during the Taconic Orogeny (Hatcher, 1978; Hatcher, 1989; Hatcher and Goldberg, 1991). Based on the presence of both eclogite and metabasalts with oceanic affinity, especially near the western margin of the terrane, researchers generally infer that its history involved subduction (i.e., model b or c) (e.g., Willard and Adams, 1994; Stewart and others, 1997; Thomas, 2001).

If subduction did in fact occur, then by analogy with modern and paleosubduction zones the Piedmont Terrane should contain an assemblage of plutonic rocks with a wide range in composition, including abundant intermediate lithologies. Yet though the southern Appalachian orogen of western North Carolina and northern Georgia does contain common felsic intrusive rocks, intermediate plutonism appears to be rare (cf. Miller and others, 1997; Vinson and others, 1999). To our knowledge the only example of intermediate plutonism in this region is the Persimmon Creek Gneiss (PCG), a metamorphosed pluton in the Eastern Blue Ridge Belt of the Piedmont Terrane (Hatcher, 1979). Its composition thus suggests that it may reflect subduction-related magmatism. The goal of this study is to describe the PCG, suggest a possible environment of formation, and consider its implications for the history of the Southern Appalachian orogen as a whole.

GEOLOGIC SETTING

The PCG straddles the North Carolina-Georgia border in the Eastern Blue Ridge portion of the Piedmont Terrane (Figure 1). It intrudes the Coleman River and the Ridgepole Mountain formations, metasedimentary units of the Coweeta Group that are exposed in the Soque River/Hayesville thrust sheet. Prime exposures of the approximately 130 km^2 pluton are found

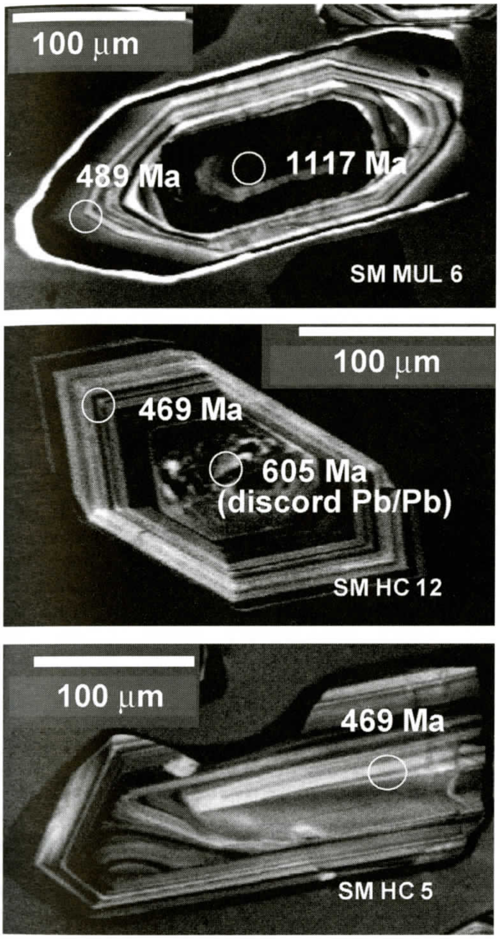


Figure 5. Cathodoluminescence images of zircons separated from Persimmon Creek Gneiss showing typical zoning. Ages are $^{206}Pb/^{238}U$, except for $^{207}Pb/^{206}Pb$ age of one highly discordant core (probably actually Grenville age).

least in part the epidote crystallized from magma rather than as a metamorphic mineral (Zen and Hammarstrom, 1984; Keane and Morrison, 1997).

Although most exposures of PCG are relatively homogeneous, some are heterogeneous and preserve evidence for interactions between contrasting lithologies. Screens and xenoliths of metasedimentary Coleman River Formation appear to have disaggregated and partially dissolved into the PCG, contaminating the host as indicated by locally abundant garnet and more siliceous and peraluminous compositions (Figure 4a,b). Hornblende-rich mafic enclaves are common in some areas and are especially abundant where dioritic to gabbroic magmas appear to have mingled with the main PCG magma as extensive sheets and larger enclaves (Figure 4c,d). Hornblende is present only in these areas and may reflect hydridization.

AGE AND ZIRCON INHERITANCE

Zircons extracted from two samples of the PCG for this study, like those from the previously studied sample P22 (Miller and others, 2000), are typically euhedral and moderately elongate and are marked by strong, oscillatory zoning that strongly indicates magmatic growth (Figure 5). Grains from P22 and new sample CPCMUL contain almost ubiquitous, well-defined cores with magmatic overgrowths. Though fairly common, cores are much less abundant in zircons from sample PCHC than in the other two samples.

Thirty five apparent ages of analyzed spots from what appear to be magmatic zones (concentric, euhedral, oscillatory) range from 414 to 510 Ma, with 2σ between ~±7 and 23 Ma (Table 1; Figure 6). In each sample, these ages can be divided into three groups: 489-510 Ma (4 total analyses); 455 and 477 Ma (21, the majority); and younger "ages" of 414-454 Ma (10 analyses). The younger ages almost certainly indicate partial Pb loss or local recrystallization, and the older ages may represent an inherited component derived from rocks formed during a slightly older magmatic episode. We interpret the bulk of the ages to indicate the true crystallization age.

The twenty-one ages between 455 and 477 Ma, when pooled, yield an age of 468 ± 3 Ma (MSWD 1.8). Individual samples differ marginally if their ages are taken alone [P22 (9 analyses) 468 ± 3 Ma (MSWD 3.0), CPCMUL (5 analyses) 464 ± 6 Ma (MSWD 1.0), and PCHC (7 analyses) 468 ± 6 Ma (MSWD 0.8)], and the populations differ slightly in a probability plot (Fig. 6c). Nonetheless, ages of all three samples are clearly very similar, and ages within error and relatively low MSWD for the pooled analyses suggest that all reflect the same crystalliza-

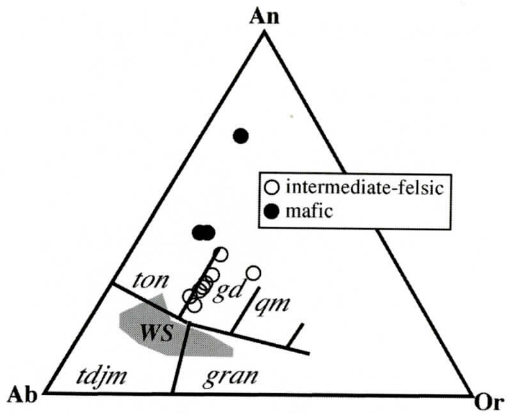


Figure 3. Normative feldspar compositions of Persimmon Creek Gneiss with classification scheme of Barker (1979). Abundant biotite in samples is reflected in relatively high normative Or (granodiorites in the norm-based scheme are modal tonalites). Samples characterized as mafic are a gabbro and two diorites with <10% normative quartz. *ton:* tonalite; *gd:* granodiorite; *qm:* quartz monzonite; *tdjm:* trondhjemite; *gran:* granite.

minescent populations correspond to textural variants and suggest multiple episodes of plagioclase formation in response to magmatic, metamorphic/deformational, and hydrothermal events.

Typical samples of PCG contain approximately 60-65% plagioclase, 20% quartz, 10-15% biotite, and minimal potassium feldspar and are thus modally tonalites. In terms of their norms, these samples lie on the boundary between granodiorite and tonalite (Figure 3), with the shift toward normative Or resulting from the fact that most K and therefore most Or component is in biotite. A few samples are more mafic, with less quartz and abundant hornblende, and are classified as diorites and hornblende gabbros. Epidote is present in most samples; muscovite occurs in the more felsic rocks; and hornblende is restricted to mafic rocks. Garnet is present locally (see below). Allanite, apatite, sphene, and zircon are common accessory minerals. Epidote is relatively abundant (up to 5%), commonly occurring as subhedral prisms (Figure 2b) or as rims around euhedral to subhedral allanite. Subhedral morphology, euhedral zoning marked by variations in birefringence, and the presence of allanite cores suggests that at

Figure 4. Exposures of Persimmon Creek Gneiss; pencil for scale. (a) Septum of garnet-rich metasedimentary rock enclosed and injected by Persimmon Creek Gneiss; arrow points to coarse garnet-rich zone. (b) Close-up of garnet-rich zone in (a). (c) Mafic sheet (arrow) separating coarser and finer variants of Persimmon Creek Gneiss. (d) Enclave of dioritic material in Persimmon Creek Gneiss.

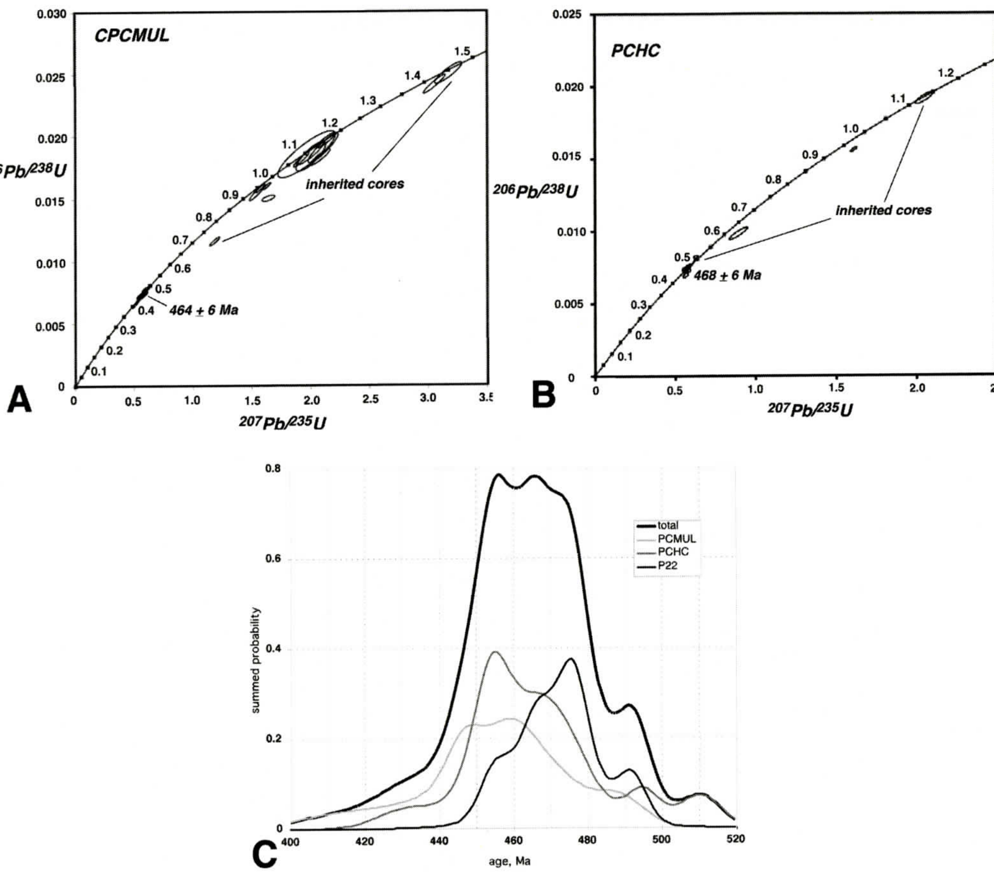


Figure 6. U-Pb data. (a) Concordia plot, sample CPCMUL. (b) Concordia plot, sample PCHC. (c) Summed Gaussian probability distributions (Deino and Potts, 1992) for all analyses of each sample, including P22 (Miller and others, 2000), and all samples combined.

SiO_2) are peraluminous, whereas the more mafic samples are metaluminous. Sample PCBC2, from a screen heavily contaminated by metasedimentary material, is geochemically distinct from the other samples, with the highest SiO_2 (the only sample with >70% SiO_2) and Zr and lowest K_2O, Na_2O, CaO, Sr, and Al_2O_3 concentrations of any sample, along with unusually low Rb and high Fe for so silicic a rock. The most mafic sample, hornblende gabbro PC-GAB, is also distinctive, with very high CaO and MgO and very low Na_2O and K_2O, as well as generally low incompatible element concentrations. The other samples possess moderate concentrations of K_2O (1.5-3.3 wt%) and Sr (320-540 ppm), moderate but variable light rare earth element (LREE) enrichment (~50-150 x chondrite), a flat heavy rare earth (HREE) pattern at ~10 x chondrite, and modest but distinct negative Eu anomalies (Figure 8a). All samples also exhibit depletion in high field strength elements (HFSE) including Ta, Nb, P, and Ti (Figure 8b) and plot in the volcanic arc granite field on tectonic discrimination diagrams (e.g. Figure 9).

Initial ε_{Nd} values of the three samples analyzed range from –4.1 to –4.9, and initial $^{87}Sr/^{86}Sr$ ratios from 0.7081 to 0.7091 (Table 2). The compositions cluster near the primitive end (high ε_{Nd}, low $^{87}Sr/^{86}Sr$) of the fields for basement gneisses and metasedimentary rocks of the Piedmont Terrane, displaced slightly toward the field of mafic rocks of the Eastern Blue Ridge (B. Bream and P. Fullagar, unpub. data; Thomas, 2001)(Figure 10).

Two typical samples of the PCG have $\delta^{18}O$

Table 1. U-Pb zircon data for Persimmon Creek Gneiss samples.

analysis	Age (Ma) $^{206}Pb/^{238}U$	Age (1 s.e.) $^{206}Pb/^{238}U$	Age (Ma) $^{207}Pb/^{235}U$	Age (1 s.e.) $^{207}Pb/^{235}U$	Age (Ma) $^{207}Pb/^{206}Pb$	Age (1 s.e.) $^{207}Pb/^{206}Pb$	$^{206}Pb/^{238}U$	1 s.e. $^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	1 s.e. $^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	1 s.e. $^{207}Pb/^{206}Pb$	Radiogenic ^{206}Pb (%)
sample PCMUL:													
MUL_1_sp1	708	10	794	10	1042	14	0.11610	0.00177	1.1850	0.02132	0.07404	0.00051	99.86
MUL_2_sp1	476	9	471	9	444	36	0.07662	0.00146	0.5894	0.01391	0.05579	0.00090	99.93
MUL_3_sp1	1440	22	1451	14	1467	15	0.25020	0.00434	3.1730	0.05765	0.09197	0.00074	99.88
MUL_4_sp1	462	6	473	7	524	25	0.07436	0.00095	0.5930	0.01070	0.05784	0.00067	100.00
MUL_3_sp2	414	12	422	10	463	18	0.06636	0.00194	0.5148	0.01545	0.05627	0.00045	99.87
MUL_5_sp1	948	10	960	8	986	9	0.15840	0.00173	1.5730	0.01915	0.07201	0.00032	99.99
MUL_5_sp2	451	7	450	11	450	54	0.07238	0.00125	0.5581	0.01734	0.05593	0.00135	99.56
MUL_6_sp1	1074	16	1089	12	1117	12	0.18130	0.00301	1.9210	0.03334	0.07685	0.00044	99.70
MUL_6_sp2	489	7	487	7	477	23	0.07882	0.00109	0.6155	0.01127	0.05664	0.00058	99.99
MUL_7_sp1	903	7	986	11	1176	25	0.15040	0.00127	1.6420	0.02731	0.07914	0.00100	98.05
MUL_8_sp1	471	7	466	6	445	27	0.07571	0.00111	0.5826	0.01009	0.05581	0.00069	99.96
MUL_9_sp1	1088	32	1117	21	1173	38	0.18380	0.00590	2.0030	0.06292	0.07905	0.00153	99.91
MUL_10_sp1	1125	32	1151	21	1202	25	0.19060	0.00590	2.1080	0.06433	0.08019	0.00103	99.90
MUL_11_sp1	458	6	463	7	487	26	0.07362	0.00097	0.5774	0.01015	0.05688	0.00068	99.98
MUL_12_sp1	958	8	982	7	1035	8	0.16020	0.00140	1.6290	0.01682	0.07377	0.00030	99.98
MUL_12_sp1 @1	1100	24	1114	19	1143	23	0.18600	0.00445	1.9970	0.05596	0.07784	0.00092	99.79
MUL_14_sp1	1393	20	1421	12	1463	9	0.24130	0.00383	3.0530	0.04657	0.09177	0.00044	99.93
MUL_15_sp1	449	9	449	8	449	30	0.07206	0.00145	0.5556	0.01287	0.05592	0.00077	99.89
MUL_16_sp1	460	9	458	10	449	31	0.07399	0.00152	0.5703	0.01509	0.05590	0.00079	99.91
MUL_17_sp1	446	5	444	4	431	18	0.07171	0.00077	0.5483	0.00679	0.05546	0.00044	99.94
MUL_18_sp1	1097	51	1104	42	1119	64	0.18550	0.00936	1.9670	0.12240	0.07692	0.00247	99.77
MUL_19_sp1	434	9	438	8	458	22	0.06965	0.00155	0.5391	0.01223	0.05614	0.00055	100.00
MUL_20_sp1	1093	10	1143	7	1240	7	0.18470	0.00176	2.0830	0.02014	0.08179	0.00028	99.97
MUL_21_sp1	1085	18	1143	14	1255	16	0.18330	0.00334	2.0820	0.04314	0.08242	0.00067	99.94
MUL_22_sp1	1158	17	1159	14	1162	16	0.19670	0.00312	2.1320	0.04212	0.07860	0.00064	99.94
MUL_23_sp1	929	18	949	14	996	15	0.15500	0.00329	1.5460	0.03373	0.07234	0.00054	99.62
sample PCHC:													
HC_1_sp1	936	9	975	8	1063	13	0.15620	0.00168	1.6110	0.02010	0.07481	0.00047	99.94
HC_2_sp1	475	7	470	8	446	42	0.07653	0.00110	0.5892	0.01190	0.05583	0.00106	99.90
HC_2_sp2	477	8	476	8	469	24	0.07677	0.00130	0.5974	0.01330	0.05643	0.00060	99.94
HC_3_sp1	453	7	459	6	490	25	0.07274	0.00113	0.5713	0.00928	0.05697	0.00065	99.95
HC_4_sp1	454	5	456	8	462	41	0.07302	0.00080	0.5661	0.01270	0.05623	0.00105	99.91
HC_5_sp1	469	9	460	11	418	44	0.07541	0.00143	0.5734	0.01670	0.05514	0.00110	99.79
HC_6_sp1	455	4	452	6	436	26	0.07306	0.00070	0.5600	0.00862	0.05559	0.00064	99.96
HC_7_sp1	451	7	466	9	539	46	0.07254	0.00115	0.5826	0.01390	0.05826	0.00122	99.96
HC_8_sp1	495	5	489	4	463	9	0.07981	0.00080	0.6191	0.00598	0.05627	0.00024	99.87
HC_8_sp2	511	6	494	9	419	40	0.08240	0.00093	0.6267	0.01410	0.05516	0.00098	99.23
HC_9_sp1	1128	23	1132	19	1138	28	0.19120	0.00416	2.0480	0.05550	0.07767	0.00108	99.87
HC_10_sp1	466	7	463	8	451	36	0.07491	0.00119	0.5780	0.01270	0.05596	0.00090	99.92
HC_11_sp1	458	7	450	10	407	52	0.07363	0.00120	0.5570	0.01580	0.05486	0.00128	99.76
HC_12_sp1	605	25	648	31	799	64	0.09846	0.00425	0.8926	0.05800	0.06575	0.00201	99.98
HC_12_sp2	469	9	463	9	436	40	0.07547	0.00142	0.5783	0.01460	0.05558	0.00100	99.84
HC_13_sp1	433	8	454	10	564	54	0.06940	0.00140	0.5636	0.01570	0.05891	0.00145	99.98
HC_14_sp1	466	6	467	8	474	29	0.07497	0.00103	0.5846	0.01200	0.05656	0.00073	100.00

^{204}Pb correction for common Pb analysis labels (e.g. **MUL_1_sp1**) refer to sample, zircon grain, and point on zircon; "**@1**" indicates repeat analysis at same spot

tion age.

Ages of inherited cores are also similar among the three samples (Figure 6a,b; Miller and others, 2000). Five variably discordant cores from P22 had $^{207}Pb/^{206}Pb$ ages of 1.0-1.4 Ga. In sample CPCMUL, 9 of the 15 analyzed cores are concordant at 1.09-1.15 Ga, two are concordant at ~ 1.4 Ga, and four are discordant but yield $^{207}Pb/^{206}Pb$ ages of 1.0-1.2 Ga. Among the sparse cores in PCHC zircons, one is concordant at 1.13 Ga and two are discordant with $^{207}Pb/^{206}Pb$ ages of 0.8 and 1.1 Ga.

GEOCHEMISTRY

The eleven analyzed samples analyzed range in SiO_2 content from 53 to 73 wt% (Table 2; Fig. 7). The more felsic samples (>58 wt%

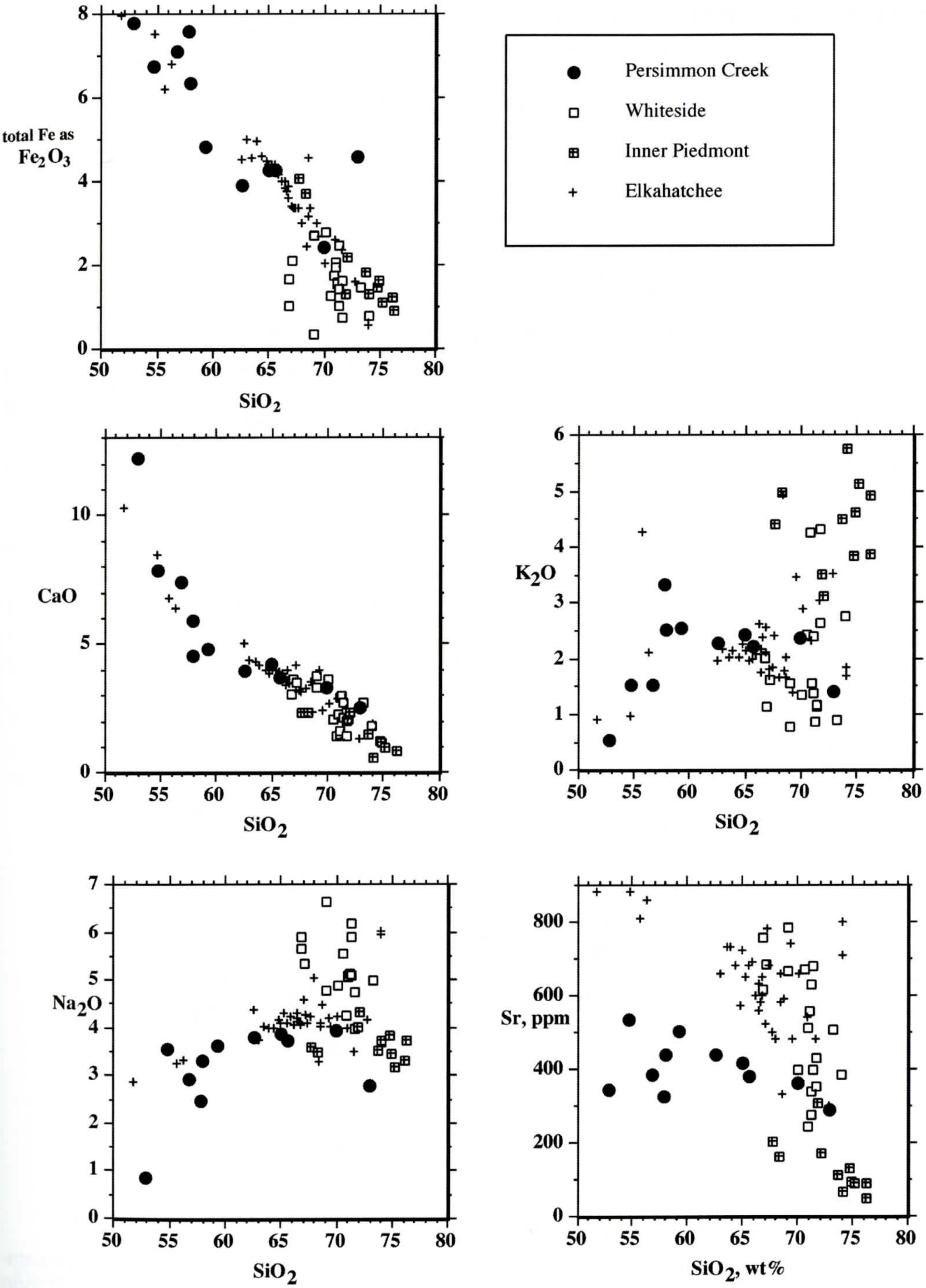


Figure 7. Harker plots comparing elemental compositions of Persimmon Creek Gneiss with those of other Ordovician plutons from the Piedmont Terrane (Whiteside pluton, Eastern Blue Ridge Belt, NC [Miller and others, 1997, and unpub. data]; Elkahatchee quartz diorite, Eastern Blue Ridge Belt, AL [Drummond and others, 1994]; Inner Piedmont plutons, NC-SC [Vinson, 1999]).

Table 2. Elemental and isotopic compositions of Persimmon Creek Gneiss samples.

	P22A	PCLU1	CPCU1	CPCMUL	PCBC2	PCHC	CPC6	PC-GAB	PCQ2	PC22B	PCPN
SiO_2, wt%	57.9	65.59	62.53	64.89	72.86	59.19	57.78	52.81	56.71	54.66	69.90
TiO_2	0.82	0.52	0.593	0.471	0.892	0.734	1.2	0.836	0.571	1.201	0.268
Al_2O_3	18.1	16.99	17.77	16.45	12.11	19.54	17.36	11.62	16.76	19.34	16.00
Fe_2O_3(total)	6.36	4.29	3.92	4.27	4.62	4.83	7.59	7.81	7.11	6.76	2.44
MnO	0.07	0.073	0.092	0.074	0.112	0.082	0.111	0.136	0.119	0.087	0.040
MgO	3.19	2.14	2.47	2.24	1.26	3.05	4.36	11.24	5.82	3.64	0.99
CaO	5.94	3.73	4.01	4.23	2.56	4.82	4.55	12.22	7.43	7.91	3.35
Na_2O	3.32	3.73	3.82	3.89	2.81	3.64	2.5	0.89	2.93	3.56	3.96
K_2O	2.52	2.23	2.3	2.45	1.42	2.57	3.33	0.54	1.54	1.54	2.38
P_2O_5	0.23	0.15	0.15	0.16	0.11	0.21	0.25	0.09	0.13	0.19	0.14
LOI	0.5	0.99	1.07	0.97	1.73	1.1	1.43	1.78	1.20	1.14	
Total	99.2	100.44	98.73	100.1	100.5	99.77	100.46	99.98	100.32	100.02	99.47
Rb, ppm	83	85	77	72	40	80	107	5	54	51	65
Sr	441	382	440	415	289	504	324	342	387	536	361
Ba	570	472	624	563	455	662	476	87	322	399	900
Y	24	11	16	23	28	21	27	27	25	33	12
Zr	240	200	183	185	338	239	150	95	173	210	121
Hf	7.7	5.2	4.8	4.9	7.3	5.3	3.5	3.4	5.2	6.3	5
Nb	7	9.6	6.1	7.9	10.3	7.4	8.6	6.1	8.3	9.7	7
Ta	0.5	0.9	0.62	0.64	0.65	0.68	0.79	0.48	0.49	0.67	0.7
V	91	66	73	61	77	84	149	228	128	192	34
Ni	21	17	21	15	17	24	23	93	45	<1	7
Cr	40	34.2	42	40.5	41	50	39.3	739	285	-0.5	16
La	44.6	29.4	53.9	31.8	25.2	19.6	29.8	21.8	17.2	16.1	17.1
Ce	90.4	58.9	110	65.3	55.4	43.1	53.4	42.8	39.6	38.8	35.1
Pr	11	6.64	12.4	7.38	6.39	5.14	6.96	7.13	5.02	5.42	4
Nd	38	25.3	46.4	28.8	28.5	24.4	30.2	34.6	22.1	27	18.5
Sm	7.1	3.99	7.64	5.26	5.33	5.12	5.58	7.78	5.27	7.19	3.6
Eu	1.57	1.00	1.38	1.07	1.22	1.21	1.42	1.83	1.27	1.77	0.96
Gd	6.6	3.32	5.87	4.53	5.06	4.47	5.17	6.73	5.01	6.73	3.3
Tb	0.9	0.48	0.72	0.66	0.73	0.64	0.79	0.99	0.84	1.2	0.4
Dy	4.8	2.94	3.33	3.58	4.18	3.05	4.33	5.26	5.04	7.34	2.6
Ho	1	0.49	0.58	0.74	0.86	0.51	0.82	0.95	0.99	1.44	0.4
Er	2.5	1.29	1.42	2.1	2.6	1.29	2.26	2.68	2.95	4.11	1.3
Tm	0.4	0.204	0.205	0.332	0.4	0.169	0.331	0.37	0.443	0.595	0.1
Yb	2.3	1.18	1.18	2.14	2.58	0.99	2.06	2.25	2.82	3.77	1.1
Lu	0.36	0.187	0.154	0.306	0.409	0.138	0.304	0.32	0.422	0.545	0.14
Th	6.9	7.05	11.7	10.8	7.38	3.59	5.2	4.88	2.33	1.49	3.8
U	1.1	0.89	0.89	1.43	1.01	0.73	1.3	1.9	0.96	0.49	2.6
$^{87}Rb/^{86}Sr$	-	-	-	0.467	-	0.468	-	-	-	0.230	-
$^{87}Sr/^{86}Sr_{(0)}$	-	-	-	0.7113	-	0.7122	-	-	-	0.7096	-
$^{87}Sr/^{86}Sr_{(t)}$	-	-	-	0.7082	-	0.7091	-	-	-	0.7081	-
$^{147}Sm/^{144}Nd$	-	-	-	0.1115	-	0.1373	-	-	-	0.1635	-
$^{143}Nd/^{144}Nd_{(0)}$	-	-	-	0.51216	-	0.5122O	-	-	-	0.51233	-
$^{143}Nd/^{144}Nd_{(t)}$	-	-	-	0.51182	-	0.51178	-	-	-	0.51182	-
$\varepsilon_{Nd(0)}$	-	-	-	-9.32	-	-8.49	-	-	-	-6.07	-
$\varepsilon_{Nd(t)}$	-	-	-	-4.21	-	-4.92	-	-	-	-4.08	-
$\delta^{18}O$, ‰	-	-	-	7.6	11.2	8.2	-	-	-		-

(o): present day; (t): initial

values of 7.6 and 8.2 ‰, fairly characteristic for intermediate to felsic rocks. A third sample, PCBC2, which appears in the field to be severely contaminated by metasediment, has a much higher $\delta\,^{18}O$ value of 11.2 ‰.

COMPARISONS WITH OTHER ORDOVICIAN AGE PLUTONS IN THE PIEDMONT TERRANE

Other Ordovician plutons of the Piedmont Terrane of NC-SC-GA (the Whiteside pluton of the Eastern Blue Ridge Belt [Miller et. al, 1997]

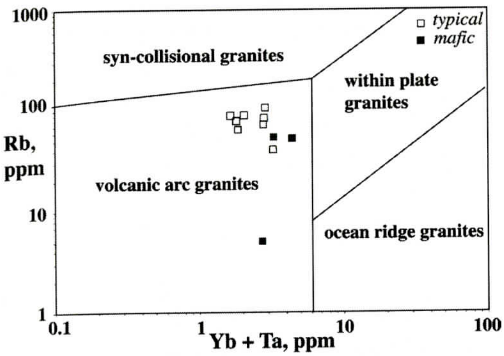


Figure 9. Persimmon Creek Gneiss samples plotted on Rb vs. Yb + Ta tectonic discrimination diagram of Pearce and others (1984).

and plutons in the Inner Piedmont Belt [Vinson, 1999; Vinson and others, 1999]) are distinct from the PCG in several respects:

(1) Both Whiteside and the Inner Piedmont plutons are more felsic and have a narrower range of SiO_2 concentration, from 66-75 wt% (Figure 7).

(2) The Whiteside pluton has much lower HREE concentrations than the PCG (Figure 11) and many samples have positive rather than negative Eu anomalies (Miller and others, 1997). Inner Piedmont plutons have higher LREE and HREE and larger negative Eu anomalies (Vinson and others, 1999; Vinson, 1999). Whiteside tends to have lower incompatible element concentrations and the Inner Piedmont plutons higher incompatible element concentrations than PCG.

(3) Despite being more mafic, the PCG is more isotopically evolved than either the Whiteside or Inner Piedmont plutons (lower ε_{Nd}, generally higher initial $^{87}Sr/^{86}Sr$) (Fig. 10).

(4) Also despite being more mafic, the PCG has markedly lower Sr concentrations than the Whiteside pluton. Inner Piedmont plutons, on the other hand, are much poorer in Sr (Figure 11).

(5) Most Harker diagrams do not indicate any coherent patterns, and by implication petrogenetic relationships, that include both the PCG and either of the other data sets (Figure 7).

INTERPRETATION

General Tectonic Environment of Formation

The petrologic characteristics of the PCG are

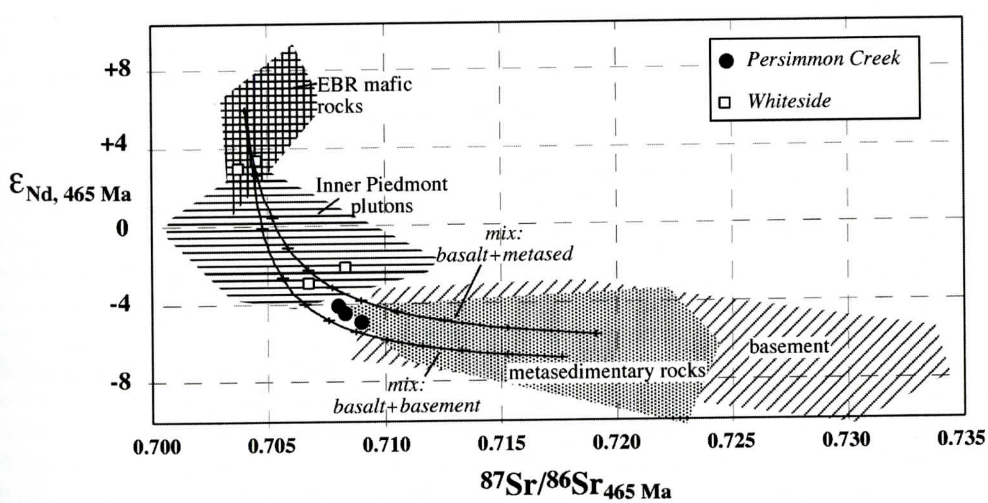


Figure 10. Initial Sr and Nd isotopic ratios of Persimmon Creek Gneiss and Whiteside pluton samples compared to major lithologies of the Piedmont Terrane at 465 Ma (Fullagar, Bream, Carrigan, Vinson, and Thomas, unpub. data). Mixing models involving island arc basalt + average Piedmont Terrane metasediment and IAB + average basement shown for comparison. Arc basalt has isotopic composition of typical Eastern Blue Ridge mafic rocks (ε_{Nd} +6, $^{87}Sr/^{86}Sr$ 0.704; 10 ppm Nd, 500 ppm Sr); metasediment: -5.6, 0.719; 36 ppm, 164 ppm; basement: -6.8, 0.7175; 82 ppm, 268 ppm. Tick marks on mixing curves represent 10% increments of end members.

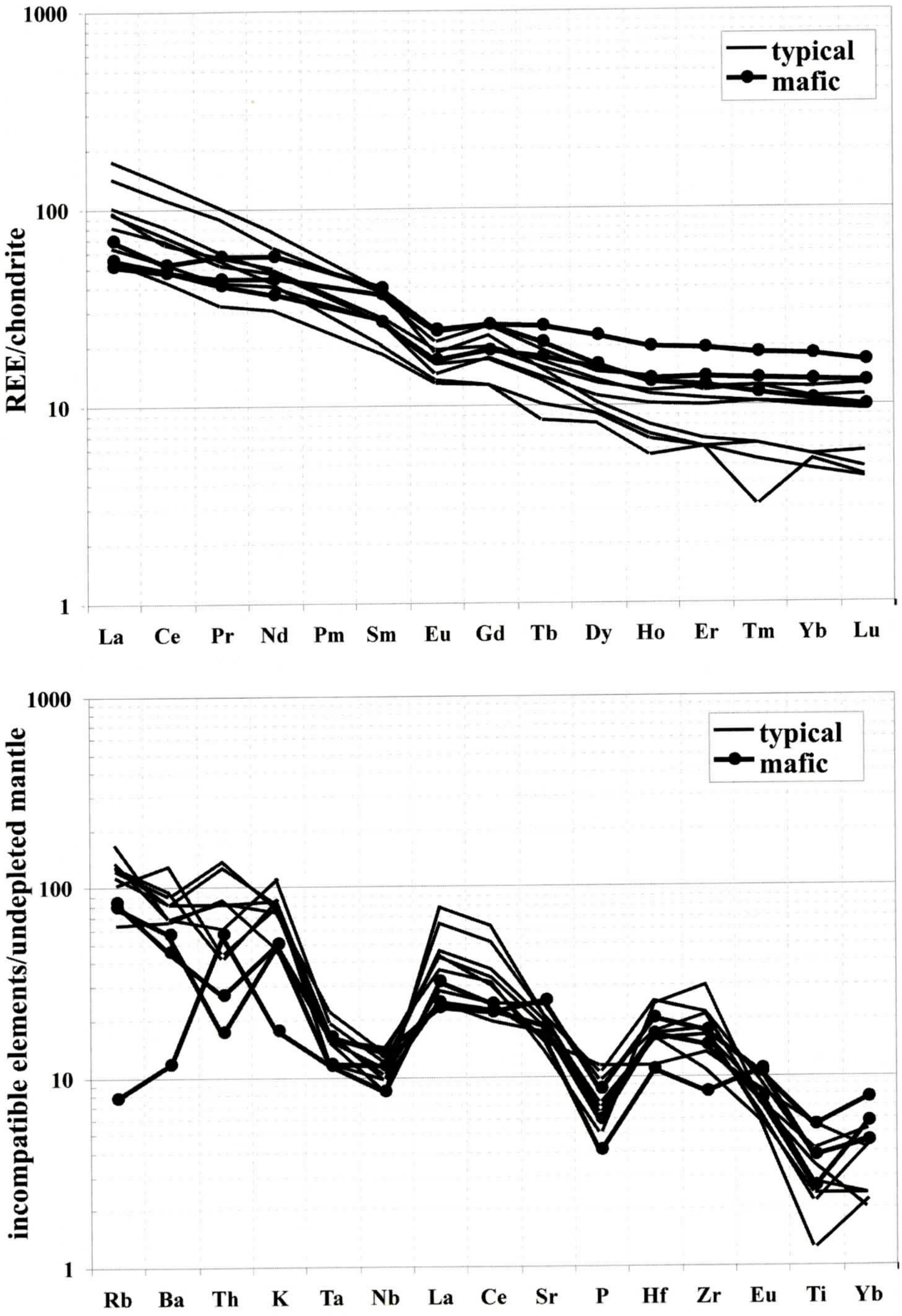


Figure 8. (a) Chondrite-normalized rare earth element plots for Persimmon Creek Gneiss samples. (b) Undepleted mantle-normalized (Sun and McDonough, 1989) spider plots for Persimmon Creek Gneiss samples.

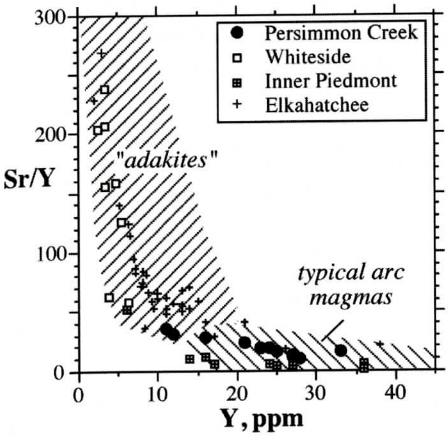


Figure 11. Sr/Yb vs. Yb discrimination diagram, comparing Piedmont Terrane Ordovician plutonic rocks to "adakites" (equilibrated at deep levels with garnet-rich, feldspar-poor residues) and modern arc and granitic rocks (Drummond and Defant 1990; Defant and Drummond 1990; Defant and others 1991; Yogodzinski and others 1995).

hatchee "Quartz Diorite," like the PCG, includes mafic to felsic rocks and is dominantly tonalitic (Figure 7; Drummond et al, 1994, 1997)(though it shares the Whiteside high Sr, low HREE - Figure 11). The Elkahatchee is the largest intrusive complex exposed in the eastern Blue Ridge (880 km^2) and is interpreted to be subduction-related.

That intermediate plutonism appears to be rare in Georgia, North Carolina, and South Carolina, but perhaps more substantial farther southwest, might be explained by a variation on model (c), described in the introduction: perhaps the small ocean basin created when the Piedmont terrane rifted from Laurentia narrowed from the southwest to the northeast (analogous to the modern Red Sea or Gulf of California) (cf. Thomas and others, 2001). When spreading ceased and convergence commenced, more oceanic crust would have been available for subduction in the southwest than in the northeast, and thus more voluminous plutonism ensued in those areas.

CONCLUSIONS

Mineralogy, field relationships, and geochemistry are consistent with the hypothesis that the Persimmon Creek Gneiss was generated in a subduction zone and emplaced at depth. Significant amounts of inherited zircon and the evolved isotopic compositions of the rocks are somewhat anomalous for this setting but do not necessarily contradict the hypothesis. Rather, the data simply indicate extensive interaction between mafic magma and evolved, deep middle crust. If the Persimmon Creek Gneiss is, in fact, subduction related, then its age of 468 Ma marks the earliest possible time of accretion of the Piedmont Terrane to Laurentia. Finally, the scarcity of intermediate plutonism in the Piedmont Terrane of North Carolina, South Carolina, and Georgia, and the more voluminous intermediate plutonism in the corresponding regions of the southwesternmost Appalachians, may constrain the geometric and tectonic character of the subduction zone and the ocean basin that it consumed.

ACKNOWLEDGEMENTS

We thank Robert Hatcher, Jr., Charles Carrigan, Christopher Thomas, John Ayers and Trent McDowell for help in field and lab work and regional tectonic insights. Thanks also to Sorena Sorensen for help with cathodoluminescence investigation. Funding was provided by the Eugene H. Vaughan, Jr., research fellowship grant (administered by Vanderbilt University, Department of Geology) and by NSF grant #EAR-9814801.

REFERENCES

Barker, F., 1979, Trondhjemite: Definition, environment and hypotheses of origin: in Barker, F., ed., Trondhjemites, dacites, and related rocks: Elsevier, Amsterdam, p. 1-12.

Bream, B.R., Hatcher, R.D. Jr., Miller, C.F., Carrigan, C.W., and Fullagar, P.D., 2001a, Provenance and geochemistry of Late Proterozoic southern Appalachian crystalline core paragneisses, NC-SC-GA-TN: Geological Society of America, Abstracts with programs 33(6): A29.

Bream, B.R., Hatcher, R.D., Jr., Miller, C.F., and Fullagar, P.D., 2001b, Geochemistry and provenance of Inner Piedmont paragneisses, NC and SC: Evidence for an internal terrane boundary?: Geological Society America, Abstracts with programs 33(2): A65.

generally consistent with formation in a subduction zone environment. It exhibits compositions ranging from mafic to felsic and comprises especially abundant intermediate rocks, as is typical for rocks generated in this setting. It also has the subduction zone elemental signature of HFSE depletion. The abundance of apparently primary hydrous mafic silicates (biotite, epidote, local hornblende) and absence of anhydrous mafic minerals is also consistent with a subduction zone setting.

Other attributes of the PCG are distinctive for a subduction-related pluton. The extreme abundance of inherited zircon contrasts sharply with most plutons that form as a direct consequence of subduction processes. Furthermore, the isotopic composition of the PCG is highly evolved for an Ordovician pluton of intermediate composition, demonstrating that it has a major mature crustal component and that it was not formed in a primitive arc.

Petrogenesis

The following model for PCG petrogenesis appears to be consistent with the data and observations presented above. (1) Magma generated in the mantle wedge of a subduction zone intruded into tectonically emplaced, metasedimentary and basement rock in the deep crust. (2) Partially melted country rock then mixed with the crystallizing mafic material to produce a crystal-rich hybrid mush with an intermediate composition. (3) Further influxes of mafic magma were incorporated as enclaves or dike-like sheets. The magma, cooled by the hybridization process, did not remain hot enough to completely dissolve the zircon already present in the crustal contaminant, so new zircon nucleated around the older grains during crystallization. The hydrous, epidote-bearing assemblage supports emplacement as a relatively cool, wet, oxidized magma in the deep middle crust (>~6 kbar?) (Schmidt and Thompson, 1996).

Such a model can be tested using the Sr and Nd isotopic compositions of the PCG and pre-Ordovician rocks of the Piedmont Terrane (Bream and others, 2001a,b; Carrigan, 2000; Fullagar, Bream, and Carrigan, unpub. data). Figure 10 demonstrates that simple mixtures of a mafic component with regional basement and metasedimentary rocks of the Eastern Blue Ridge Belt can provide reasonable matches for isotopic compositions and trend of the PCG samples. These models suggest that PCG contains roughly 50% of the primitive (~subduction zone) component.

Constraints on Paleozoic Tectonics

The age of the PCG constrains the time at which the Piedmont Terrane accreted to Laurentia. If the pluton was emplaced during subduction that preceded accretion, then accretion must have occurred later than ~468 Ma. Alternatively, it may have been emplaced during final closure of the ocean basin that presumably separated some or all of the Piedmont Terrane from autochthonous Laurentia. In this case, the age of the pluton approximates the initiation of accretion.

It is noteworthy that volcanic sequences of identical age are abundant immediately to the southwest in Georgia and Alabama in the structurally underlying Dahlonega Gold Belt and its possible equivalents (Thomas and others, 2001; McLellan and Miller, 2000). These volcanic sequences are thought to mark subduction related arcs.

Implications of Intermediate Plutonism for Southern Appalachian Tectonics

The PCG appears to be the only pluton with intermediate composition or direct evidence for involvement of mafic magma in the Piedmont Terrane of North Carolina, South Carolina, and Georgia. Other plutons in this region are more felsic and geochemical data suggest a very different petrogenetic history from the PCG. For example, although the Whiteside pluton is isotopically primitive, it is far more felsic and its high Sr and low HREE suggest an entirely crustal derivation from a deep (garnet-bearing, feldspar-poor) mafic source (Miller and others, 1997), (Figure 7, 11). The Inner Piedmont plutons are also much more felsic and appear to lack entirely a mafic component.

Farther southwest, in Alabama, the Elka-

Thomas, C.W., 2001, Origins of mafic-ultramafic complexes of the Eastern Blue Ridge province: Geochronological and geochemical constraints: unpub. Master's thesis, Vanderbilt University, Nashville, TN, 154 p.

Thomas, C.W., Miller, C. F., Fullagar, P. D., Meschter McDowell, S. M., Vinson, S. B., and Bream, B. R., 2001, Where Is the Arc?, Discontinuities in Taconian Arc Magmatism in the Southern Appalachians: Geological Society of America, Abstracts with programs 33(6): A262.

Thomas, C.W., C.F. Miller, B.R. Bream, and P.D. Fullagar, 2001, Origins of mafic-ultramafic complexes of the eastern Blue Ridge, Southern Appalachians: Geochronologic and geochemical constraints: Geological Society of America, Abstracts with programs, v. 33, no. 2, p. A-66.

Vinson, S.B., 1999, Ion probe geochronology of granitoid gneisses of the Inner Piedmont, North Carolina and South Carolina: unpub. Master's thesis, Vanderbilt University, Nashville, TN, 84 p.

Vinson, S.B., Miller, C.F., Fullagar, P.D., R.D. Hatcher, and C. Coath, 1999, Constraints on timing of Inner Piedmont plutonism, NC-SC, from ion microprobe U-Pb zircon analysis: Geological Society of America, Abstracts with programs 31(3): A30

Willard, R.A., and Adams, M.G., 1994, Newly discovered eclogite in the southern Appalachian orogen, northwestern North Carolina: Earth and Planetary Science Letters, v. 123, p. 61-70.

Williams, H. and Hatcher, R.D., Jr., 1983, Suspect terranes: a new look at the Appalachian orogen: in Hatcher, R.D., Jr., Williams, H., and Zietz, I., eds., Contributions to the Tectonics and Geophysics of Mountain Chains: Geological Society of America Memoir 158.

Yogodzinski, G. M., Kay, R. W., Volynets, O. N., Koloskov, A. V., Kay, S. M., 1995, Magnesian andesite in the western Aleutian Komandorsky region; implications for slab melting and processes in the mantle wedge: Geological Society of America Bulletin, v. 107, p. 505-519.

Zen, E. and Hammarstrom, J.M., 1984, Magmatic epidote and its petrologic significance: Geology, v. 12, p. 515-518.

Carrigan, C.W., 2000, Ion microprobe geochronology of Grenville and older basement in the southern Appalachians: unpub. Master's thesis, Vanderbilt University, Nashville, TN, 101 p.

Drummond, M.S., Neilson, M.J., Allison, D.T., and Tull, J.F., 1997, Igneous petrogenesis and tectonic setting of granitic rocks from the eastern Blue Ridge and Inner Piedmont, Alabama Appalachians: in Sinha, A.K., Whalen, J.B., and Hogan, J.P., eds., The Nature of Magmatism in the Appalachian Orogen: Boulder, Colorado, Geological Society of America Memoir 191, p.147-164.

Defant, M.J., and Drummond, M.S., 1990. Derivation of some modern arc magmas by melting of young subducted lithosphere: Nature, v. 347, p. 662-665.

Defant, M.S., Richerson, P.M., DeBoer, J.Z., Stewart, R.H., Maury, R.C., Bellon, H., Drummond, M.S., Feigenson, M.D., and Jackson, T.E., 1991: Dacite genesis via both slab melting and differentiation: Petrogenesis of La Yeguada volcanic complex, Panama: Journal of Petrology, v. 32, p. 1101-1142.

Deino, A., and Potts, R., 1992. Age-probability spectra of single-crystal $^{40}Ar/^{39}$ results: examples from Olorgesailie, southern Kenya rift: Quaternary International, v. 13/14, p. 47-53.

Drummond, M.S., and Defant, M.J., 1990. A model for trondhjemite-tonalite-dacite genesis and crustal growth via slab melting; Archean to modern comparisons: Journal of Geophysical Research, v. 95 p. 21,503-21,521.

Drummond, M.S., Allison, D.T., and Wesolowski, D.J., 1994, Igneous petrogenesis and tectonic setting of the Elkahatchee Quartz Diorite, Alabama Appalachians: Implications for Penobscottian magmatism in the eastern Blue Ridge: American Journal of Science, v. 294, p. 173-236.

Hatcher, R.D., Jr., 1978, Tectonics of the western Blue Ridge, southern Appalachians: review and speculation: American Journal of Science, v. 278, p. 276-304.

Hatcher, R.D., Jr., 1979, The Coweeta group and geosyncline: major features of the North Carolina-Georgia Blue Ridge: Southeastern Geology, v. 21, p. 17-29.

Hatcher, R.D., Jr., 1989, Tectonic synthesis of the U.S. Appalachians: in Hatcher, R.D., Jr., Thomas, W.A., and Viele, G.W., eds., The Appalachian-Ouachita orogen in the United States: Boulder, Colorado, Geological Society of America, The Geology of America, F-2, p. 511-535.

Hatcher, R.D., Jr., 1999, Digital geologic map of the Eastern Blue Ridge and part of the Inner Piedmont in northeastern Georgia, northwestern South Carolina, and southwestern North Carolina (unpublished map).

Hatcher, R.D., Jr., and Goldberg, S.A., 1991, The Blue Ridge Geological Province: in The Geology of the Carolinas: Carolina Geological Society 50th anniversary volume: Knoxville, University of Tennessee Press, p. 11-35.

Hibbard, J.P., and Samson, S.D., 1995, Orogenesis exotic to the Iapetan cycle in the southern Appalachians: in Hibbard, J.P., van Staal, C.R., and Cawood, P.A., eds., Current perspectives in the Appalachian-Caledonian orogen, Geological Association of Canada, Special paper 41, p. 191-205.

Horton, J.W., Jr., Drake, A.A., Jr., and Rankin, D.W., 1989, Tectonostratigraphic terranes and their Paleozoic boundaries in the central and southern Appalachians, in Dallmeyer, R.D., ed., Terranes in the circum-Atlantic Paleozoic Orogens: Geological Society of America Special Paper 230, p. 213-245.

Keane, S.D., and Morrison, J., 1997, Distinguishing magmatic from subsolidus epidote: laser probe oxygen isotope compositions: Contributions to Mineralogy and Petrology, v. 126, p. 265-274.

Meschter, S.M., 2001, The Persimmon Creek Gneiss, Eastern Blue Ridge, North Carolina-Georgia: Evidence for the missing arc?: unpub. Senior Honors thesis, Vanderbilt University, Nashville, TN, 43 p.

Miller, C.F., Hatcher, R.D., Jr., Ayers, J.C., Coath, C.D., and Harrison, T.M., 2000, Age and zircon inheritance of eastern Blue Ridge plutons, southwestern North Carolina and northeastern Georgia, with implications for magma history and evolution of the southern Appalachian orogen: American Journal of Science, v. 300, p. 142-172.

Miller, C.F., Fullagar, P.D., Sando, T.W., Kish, S.A., Solomon, G.C., Russell, G.S., and Wood Steltenpohl, L.F., 1997, Low-potassium, trondhjemitic to granodioritic plutonism in the eastern Blue Ridge, southwestern North Carolina-northeastern Georgia: in Sinha, A.K., Whalen, J.B., and Hogan, J.P., eds., The Nature of Magmatism in the Appalachian Orogen: Boulder, Colorado, Geological Society of America Memoir 191.

Pearce, J.A., Harris, N.B.W. and Tindle, A.G., 1984. Trace element discrimination diagrams for the tectonic interpretation of granitic rocks: Journal of Petrology, 25(4): 956-983.

Schmidt, M.W., and Thompson, A.B., 1996, Epidote in calcalkaline magmas: an experimental study of stability, phase relationships, and the role of epidote in magmatic evolution: American Mineralogist, v. 81, p. 462-474.

Shaw, H.F. and Wasserburg, G.J., 1984, Isotopic constraints on the origin of Appalachian mafic complexes: American Journal of Science, v. 284, p. 319-349.

Stewart, K.G., Adams, M.G., and Trupe, C.H., 1997, Paleozoic structural evolution of the Blue Ridge thrust complex, western North Carolina: in Stewart, K.G., Adams, M.G., and Trupe, C.H., eds., Paleozoic Structure, Metamorphism, and Tectonics of the Blue Ridge of western North Carolina: Carolina Geological Society Field trip Guidebook.

Sun, S.S. and McDonough, W.F., 1989, Chemical and isotopic systematics of oceanic basalts; implications for mantle composition and processes: in A.D. Saunders and J. Tarney (Editors), Magmatism in the Ocean Basins. Geological Society of London Special Publication 42, pp. 313-345.

SOUTHEASTERN GEOLOGY
V. 41, No. 2, July 2002, p. 119-128

PROTEROZOIC-CAMBRIAN PALEOBIOGEOGRAPHY OF THE CAROLINA TERRANE

M. A. S. MCMENAMIN

Department of Earth and Environment
Mount Holyoke College
South Hadley, MA 01075

P. G. WEAVER

North Carolina State Museum of Natural Sciences
11 West Jones Street
Raleigh, North Carolina 27601

ABSTRACT

***Pteridinium carolinaensis* (St. Jean, 1973), once interpreted as a trilobite, was shown by Gibson and others (1984) to be an Ediacaran fossil. A specimen collected from North Carolina in 1986 has distinctive radiating tubular canals emanating from axial nodes. The position of these tubes or canals is considered here to be diagnostic for the species.**

***Pteridinium carolinaensis* occurs in Baltica (White Sea region, Podolica) and Australia (Ediacara) as well as North Carolina. The distribution of *P. carolinaensis* is consistent with paleotectonic models that juxtapose Avalonian terranes against Baltica and those that postulate a paleobiogeographic link between Avalonia, Baltica and Australia (Gibson and others, 1984). Cambrian trilobite similarities between the Carolina Slate Belt and Avalonian New England (particularly a newly recognized occurrence of the solenopleurid trilobite *Braintreella* sp. in the Carolina terrane) indicate that the Carolina terrane should be grouped with the Avalonian plexus of exotic terranes.**

INTRODUCTION

Ediacaran fossils provide a fascinating glimpse into an incompletely understood era of profound evolutionary and paleobiogeographic change. The higher-level classification of these organisms is controversial, largely because the fossils themselves are lacking in features that may be unambiguously attributed to the familiar phyla. Additional specimens and new localities are required to test hypotheses regarding both the taxonomic assignment of Ediacaran fossils and their paleobiogeographic distribution.

The Carolina terrane (or Carolina Slate Belt) of Stanly County, North Carolina has produced Ediacaran body fossils as well as metazoan trace fossils (Fig. 1; Conley, 1959; Cloud and others, 1976; Gibson, 1984, 1989). Although the body fossils are rare, some are well preserved, and they show the characteristic array of homonomous or modular partitions. These partitions are interpreted as "pneu" structures by adherents to the "Vendobiont school" (Seilacher, 1989), and as protostomous segmentation by the "Animal school" of Ediacaran fossil interpretation (Gehling, 1991). For the purposes of description in this paper, we will apply the following nongenetic terms to observed morphology: "vane" and "subdivision." "Vane" will refer to contiguous (and often flattened), petaloid sections of the Ediacaran fossil on either side of the midline. Each vane is partitioned into segment-like, modular "subdivisions." These subdivisions may be either tubular or subspherical in shape.

The first North Carolina specimens were described by geologist Joseph St. Jean (1973) as posterior regions of trilobites (Fig. 2) assigned to *?Paradoxides carolinaensis*. The trilobite interpretation stood unchallenged (but see questions about the genus assignment in Secor and others [1983]) for a decade.

After a key fossil discovery in rocks of Little

Figure 3. ***Pteridinium carolinaensis*** **(elongate specimen) from Little Bear Creek, Stanly County, North Carolina. Scale bar in centimeters.**

Figure 4. ***Pteridinium carolinaensis*** **from Rock Hole Creek, Stanly County, North Carolina. This specimen is shortened for comparison to the specimen shown in Fig. 3. Evidence for a third vane in this form is visible (as a protruding extra set of spires formed by the tips of subdivisions) along the upper edge of the specimen. Scale bar in centimeters.**

2001). Dockal and Huntsman (1990, p. 288) inferred that the fossiliferous Albemarle strata were deposited in the middle part of a tempestite fan (Grazhdankin and Ivantsov, 1996). The Albemarle Group is a weakly metamorphosed volcano-sedimentary sequence thought to be the product of an active continental margin or volcanic island arc (Dockal and Huntsman, 1990), a concept in accord with the model of Keppie and others (2001) comparing peri-Gondwanan Avalonian terranes to the modern northeastern Pacific margin.

THE GLEANING MISSION SPECIMEN

R. Tucker discovered a specimen of *Pteridinium carolinaensis* in Stanly County, North Carolina in 1986 in a float block in the parking lot of Gleaning Mission Church north of Oakboro, North Carolina (Fig. 1). The specimen is 6.1 cm in length and at first glance appears to be bilaterally symmetric (Fig. 5A-5B). The midline of the specimen displays a structure more complex than the simple zigzag medial suture characteristic of many Ediacaran fossils.

In addition to the elongate subdivisions composing the broad vanes on either side of the organism, the new specimen shows at the midline a double row of subspherical structures. These structures are either a second pair of vanes consisting of very short, nearly spherical subdivisions or are swellings of the ends of the tubular subdivisions nearest the midline. Such swellings have been recognized in the Namibian species *Pteridinium simplex* and referred to as "commisurae" by Pflug (1970, his Fig. C, page 240). We prefer the former interpretation of the subspherical structures as constituting additional vanes rather than simply swellings. The two interpretations may in fact be one and the same if the swellings (commisurae) were buds en route to developing into new vanes. A specimen of the Namibian *Ernietta* (a close *Pteridinium* relative) is known to have a nascent vane growing out of its zigzag medial suture, an observation in accord with the concept of budding at the midline. In any case, in *Pteridinium carolinaensis* the boundary between the two sets of sub-

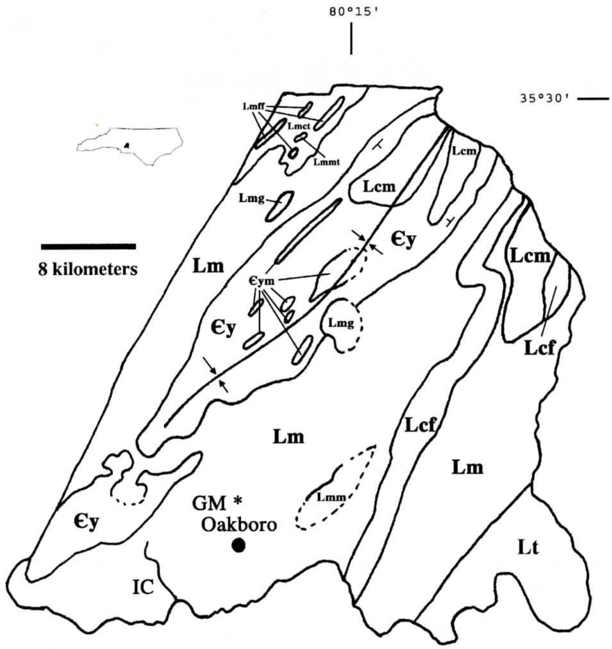


Figure 1. Generalized geologic map of Stanly County, North Carolina, Carolina terrane. Key: Lt, Tillery Formation, Lm, McManus Formation, Lmm, McManus Formation mudstone member; Lmg, McManus Formation uralitic gabbro, Lmmt, McManus Formation mafic tuff, Lmct, McManus Formation crystal tuff, Lmff, McManus Formation felsic tuff breccia; Lcm, Cid Formation mafic member, Lcf, Cid Formation felsic metavolcanics, €y, Yadkin Formation, €ym, Yadkin Formation mafic metavolcanics, IC = Island Creek; GM * = Gleaning Mission church fossil locality. Note the New London Syncline in the Yadkin formation outcrop area. Inset shows position of Stanly County in North Carolina. Geologic map data from Conley (1962), Sundelius and Stromquist (1978), Gair (1989) and Wright and Seiders (1980).

Bear Creek, S. A. Teeter initially interpreted the specimen (Fig. 3) with question as a trilobite or as a trilobite trackway (Teeter, 1983). Gibson and others (1984) subsequently assigned the fossil to the Ediacaran genus *Pteridinium.* Jenkins (1992) assigned the North Carolina specimens (Fig. 4) to *Pteridinium nenoxa* Keller 1974, but Runnegar and Fedonkin (1992) and Runnegar (1992) pointed out that *Pteridinium carolinaensis* (St. Jean, 1973) is the senior synonym of *Pteridinium nenoxa* Keller 1974.

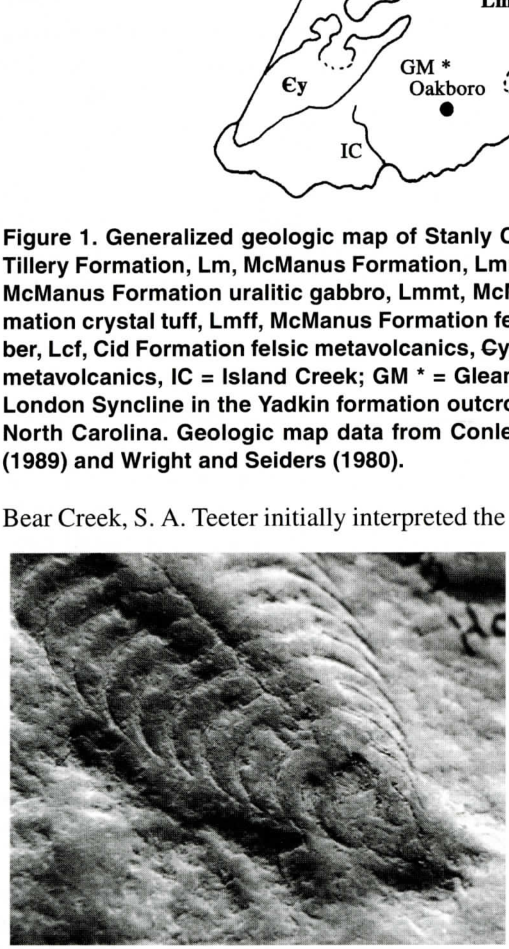


Figure 2. *Pteridinium carolinaensis* from a collection of two specimens from Island Creek, Stanly County, North Carolina, NCSM 4041. Note single subdivision at the presumed growing tip. Maximum width of the portion of specimen in view 20 mm.

The fossils occur in low grade metasedimentary rocks of the McManus Formation, consisting of clayey siltstones and thinly interbedded marine tuffs (Gibson and Teeter, 2000). Goldsmith and others (1989) used *Pteridinium carolinaensis* to provide a late Proterozoic age for the Albemarle Group in North Carolina. The Albemarle Group is equivalent (in part) to the McManus Formation (Gibson and Teeter,

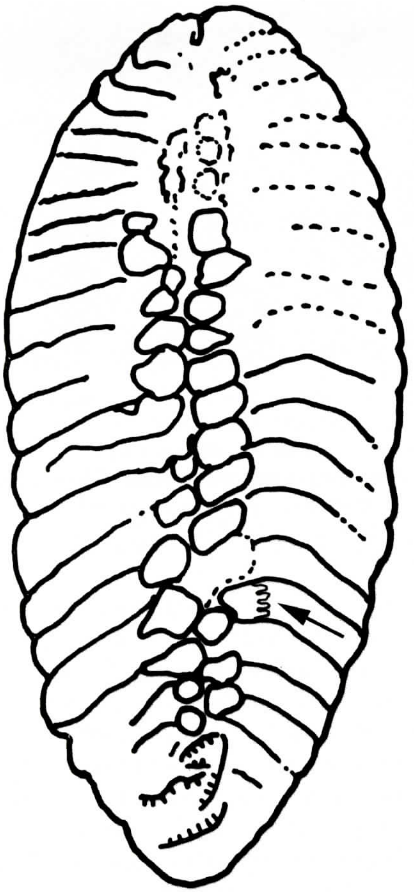


Figure 6. *Pteridinium carolinaensis.* Sketch from photograph of Gleaning Mission specimen. Note the four sets of vanes, two of which have subspherical subdivisions and two of which have curved, elongate subdivisions. Arrow shows location of Fig. 7. Length of specimen 6.1 cm.

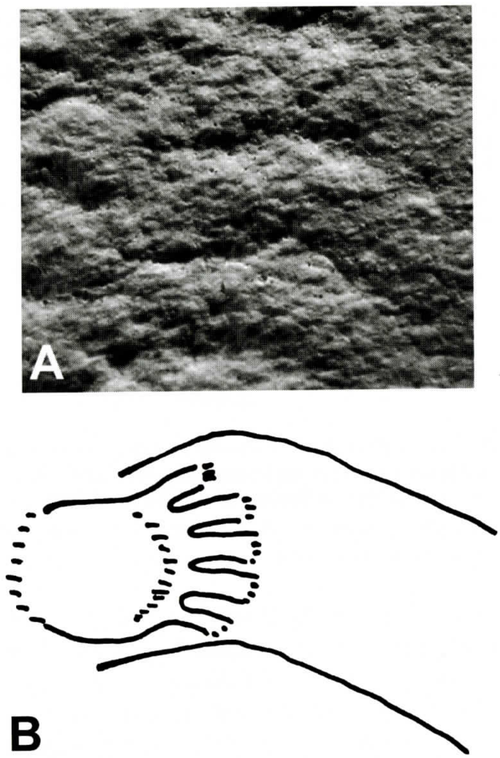


Figure 7. *A. Pteridinium carolinaensis,* radiating tubular structures associated with subspherical subdivisions. Photograph taken from plaster cast of specimen. Width of view approximately 10 mm. *B.* Sketch of radiating tubular structures associated with subspherical subdivision and medial part of nearest tubular subdivision. Width of view approximately 7 mm.

As is true of most features of Ediacaran fossils, the function of the radiating tubes in *P. carolinaensis* is uncertain. They are likely, however, to be homologous to the branching tubular structures or canals seen on other Ediacaran genera (Grazhdankin and Ivantsov, 1996) such as *Charnia* and *Ventogyrus*.

We assume here that the Gleaning Mission specimen is bipolar in the Seilacherian (1989) sense, as the subdivisions of all four vanes diminish in size in both directions along the longitudinal axis and away from the center of the specimen. The specimen shows skewness (one side of the organism shifted along the midline in a "left-lateral" sense with respect to the other side).

We interpret the zigzag aspect of the medial suture of the Gleaning Mission specimen as an authentic feature of its original structure, indicative of translational symmetry (accompanied by longitudinal slip reflection; Weyl, 1956, p. 702). Such symmetry is seen in other specimens of *P. carolinaensis* such as specimen PIN No. 3992/400 from Russia. This interpretation is in accord with the fact that the fossil locality is some distance from the Gold Hill shear zone (Gibson and Huntsman, 1988), thus the fossil matrix is unlikely to have suffered tectonic shearing.

Figure 5. ***A. Pteridinium carolinaensis.*** **Gleaning Mission specimen, NCSM 4033. Note that the tips of the vane subdivisions are obscured by matrix. Scale bar in centimeters. The locality is at Gleaning Mission Church, north of Oakboro, North Carolina, lat 34°14'13" long 80°19'6".** ***B. Pteridinium carolinaensis.*** **Gleaning Mission specimen, NCSM 4033. Length of specimen 6.1 cm.**

spherical structures forms an undulating line that is considered here to be a variant of the zigzag medial suture typical of Ediacaran fossils.

The spherical subdivisions are regularly graded in size, their diameters diminishing evenly toward either end of the organism (Figs. 5-7). One of the spherical subdivisions on the Gleaning Mission specimen developed tiny radiating tubular structures where it overlaps (as viewed in hyporelief) one of the tubular subdivisions (Figs. 5-7).

Similar structures occur on a specimen of *P. carolinaensis* from the White Sea in Russia (Fig. 8; Specimen PIN No. 3992/400; Fedonkin, 1985, 1990). Fedonkin noted in his description of this specimen (1985, p. 204; 1990, p. 338) that each tubular subdivision has an attached structure in its medial part, which may be interpreted as a pocket-shaped structure with the opening of the pocket directed away from the midline. Fedonkin (1981, 1985) further called these structures "commissural tubercles" and noted in his description of the species that these tubercles were not always present. These pockets or tubercles are apparently identical to the subspherical structures in the Gleaning Mission specimen. Fedonkin's (Fedonkin, 1985; his Plate 11, Fig. 2) photograph shows linear and perhaps branching tubular structures emanating from the open ends of the pockets. These tubular structures must therefore be homologous to the radiating tubular structures in the Gleaning Mission specimen.

In a specimen tentatively assigned to *P. carolinaensis*, Fedonkin (1981, Plate VII, Fig. 4; 1985, 1990, p. 111) identified radiating bifurcations on the distal edges of long, tubular subdivisions. Thus, it appears that both the subspherical subdivisions (commissural tubercles) and the tubular subdivisions can develop bifurcations (radiating tubular structures) on their distal edges or tips, respectively. This similarity suggests that commissural tubercles and tubular subdivisions are the same type of biological structure, differing only in overall size and shape.

and anterior border (Geyer and Landing, 2001).

The concerns expressed by Secor and others (1983; Samson and others, 1995) about inclusion of the Carolina terrane in the "Avalon zone" have been satisfied by paleobiogeographic data, and the Carolina terrane should be considered part of the Avalonian terrane group. The docking of the Carolina terrane and the closing of the Iapetus ocean in the Ordovician initiated Appalachian orogenesis (Hibbard, 2000; Bream and others, 2001).

SYSTEMATIC PALEONTOLOGY

Kingdom Vendobionta
Phylum Petalonamae
Class uncertain
Order uncertain
Family Pteridiniidae
Genus *Pteridinium* Gürich, 1933

***Pteridinium carolinaensis* (St. Jean, 1973)**
(Figs 2-8)

Synonymy:

Pteridinium cf. *simplex* Glaessner and Wade, 1966.

?Paradoxides carolinaensis St. Jean, 1973

Pteridinium nenoxa Keller, 1974 in Keller and others, 1974; Fedonkin, 1981; Sokolov and Fedonkin, 1984; Fedonkin, 1985; Fedonkin, 1990; Fedonkin, 1992; Fedonkin, 1994; Ivantsov and Grazhdankin, 1997; Fedonkin, 1998.

Pteridinium simplex Keller and Fedonkin, 1976.

Onegia nenoxa Sokolov, 1976.

Pteridinium Gibson and others, 1984; Milton, 1985; McMenamin, 1988a; McMenamin, 1988b; McMenamin and McMenamin, 1990, p. 17.

Pteridinium carolinaensis Runnegar and Fedonkin, 1992; Gibson and Teeter, 2000; Gibson and Teeter, 2001; McMenamin, 2001a, 2001b.

Type species. *?Paradoxides carolinaensis* St. Jean, 1973

Diagnosis. A bipolar Ediacaran fossil with two relatively wide and curved primary vanes. The distal tips of the primary vane subdivisions are drawn out into sharp spires. These vanes are composed of curved elongate subdivisions. Partly collapsed subdivisions may develop a relatively sharp medial keel or crest. Additional rows of subspherical subdivisions (forming a pair of short, secondary vanes) may occur at the midline edges of the primary vanes. When the subspherical subdivisions are present, tubes or canals may radiate from the outward edges of the subspherical subdivisions and away from the midline. A zigzag medial suture is developed between the paired rows of subdivisions, indicating translational symmetry with longitudinal slip reflection.

Remarks. The Gleaning Mission specimen of *P. carolinaensis* is 6.1 cm in length and 2.8 cm in width, preserved as a convex hyporelief in very fine grained sand to silt. Distal edges of subdivisions are covered by matrix and obscured from view. There are approximately 22 subdivisions composing each of the four vanes.

Pteridinium simplex differs from *P. carolinaensis* by having straighter and relatively more narrow tubular subdivisions. *P. latum* differs from both *P. simplex* and *P. carolinaensis* by having very low relief, almost flat surfaced, tubular subdivisions that are separated by very thin, shallow grooves (Fedonkin, 1985; Runnegar and Fedonkin, 1992). A cogent argument could be made, however that the differences between *P. latum* and other species of *Pteridinium* are taphonomic in nature rather than expressions of genetic difference.

Fedonkin (1985, p. 100) had this to say regarding *P. carolinaensis*:

> The description of this species is identical to that of *Pteridinium* cf. *simplex*, which was described from the Pound Quartzite of Australia (Glaessner and Wade, 1966) but differs substantially from *Pteridinium simplex* (Gürich) from the Nama Group of southwestern Africa, detailed descriptions of which are available in the writings of R. Richter and especially H. Pflug (Richter, 1955; Pflug, 1970). These species differ in the character of iterated neighboring segments, in the symmetry of paired segments across the medial line, in the form

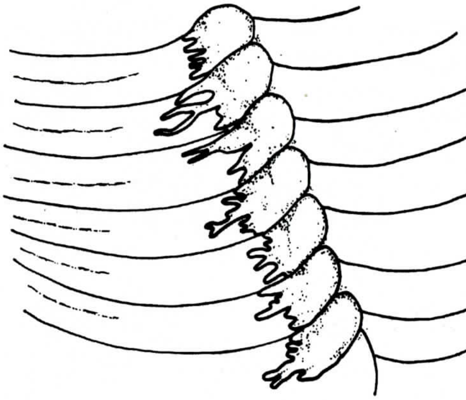


Figure 8. ***Pteridinium carolinaensis,*** **sketch of radiating canals associated with axial subspherical subdivisions. White Sea region, Russia, Specimen PIN No. 3992/400, Width of view approximately 33 mm.**

Figure 9. ***Braintreella rogersi*** **(Walcott, 1884) from the Middle Cambrian Braintree Slate, Hayward's Quarry, Massachusetts. Mount Holyoke College sample number 8309. Width of cephalon 20 mm. The genus** ***Braintreella*** **also occurs in the "Asbill Pond formation" of South Carolina.**

In considering the North Carolina specimens available to them at the time, Gibson and Teeter (1988) considered all Ediacaran body fossils from North Carolina to belong to the same taxon. They remarked (p. 267) that regardless of "overall body plan geometry," the shape of the individual subdivisions within vanes is similar, as are "the apparent articulation characteristics between segments." These comments apply equally well to the Gleaning Mission specimen.

PALEOBIOGEOGRAPHIC IMPLICATIONS

The distribution of *Pteridinium carolinaensis* has important paleobiogeographic implications. *P. carolinaensis* can now be shown to occur in Baltica (White Sea and Podolia), Australia and the Carolina Terrane. A Proterozoic paleobiogeographic link has long been suggested between Baltica and Australia (McMenamin, 1982) based on the occurrence in these regions of Ediacaran fossils such as *Tribrachidium* and *Dickinsonia*. The AustraloBaltic paleobiogeographic link was subsequently confirmed by independent PAUP (Phylogenetic Analysis Using Parsimony) tests at both the species (Franklin, 1997) and genus (Waggoner, 1999) levels.

Pteridinium carolinaensis thus belongs to the AustraloBaltic province, and further strengthens the paleobiogeographic link between Australia and Baltica at the species level. As the Carolina Terrane is the only other region known to yield this distinctive species, we find support here for the hypothesis that the Carolina Terrane was also a part of the AustraloBaltic province as first suggested by Gibson and others (1984). The best evidence currently available suggests that Australia, Baltica and the Carolina terrane were close together during the Proterozoic, perhaps as adjacent tectonic elements of Rodinia or, in the case of the Carolina terrane, post-Rodinian island arc material. This is in accordance with paleotectonic reconstructions that juxtapose Avalonia (considered here to include the Carolina terrane) and Baltica (Torsvik, 1992; Meissner and others, 1994).

Distinctive paradoxidid, solenopleurid and agraulid trilobites co-occur in both the Carolina terrane (Samson and others, 1990) and the Boston terrane (Geyer and Landing, 2001) indicating that these terranes underwent faunal interchange during the Cambrian. In particular, the solenopleurid trilobite *Braintreella* (Fig. 9) occurs in the "Asbill Pond formation" (informal name) of South Carolina. Samson and others (1990, their Fig. 6f) were uncertain as to the identification of this trilobite. We assign it here to *Braintreella* based on its tapering, subtruncate glabella and distinctive preglabellar field

Fedonkin, M. A., 1981, Belomorskaya biota venda (dokembriiskaya besskeletnaya fauna severa Russkoi platformy): Moscow, Nauka, 98 p.

Fedonkin, M. A., 1985, Sistematicheskoe opisanie vendskikh Metazoa *in* B. S. Sokolov and A. B. Ivanovskii, eds., Vendskaya Sistema. 1. Istoriko-geologicheskoe i paleontologicheskoe obosnovanie. Paleontologiya: Moscow, Akademiya Nauk SSSR, Otdelenie geologii, geofiziki i geokhimii, Moskva "Nauka," v. p. 70-106.

Fedonkin, M. A., 1990, Systematic description of Vendian Metazoa *in* B. S. Sokolov and A. B. Iwanowski, eds., The Vendian System. Vol. 1. Paleontology: Berlin, Springer-Verlag, p. 71-120.

Fedonkin, M. A., 1992, Vendian faunas and the early evolution of Metazoa *in* J. H. Lipps and P. W. Signor, eds., Origin and Early Evolution of the Metazoa: New York, Plenum Press, v. p. 87-129.

Fedonkin, M. A., 1994, Vendian body fossils and trace fossils *in* S. Bengtson, ed., Early Life on Earth: New York, Columbia University Press, v. p. 370-388.

Fedonkin, M. A., 1998, Metameric features in the Vendian metazoans: Italian Journal of Zoology, v. 65, p. 11-17.

Franklin, C., 1997, A Biogeography of the Assembly of Gondwana: unpublished Mount Holyoke College Master's Thesis, 136 p.

Gair, J. E., ed., 1989, Mineral resources of the Charlotte 1°x2° quadrangle, North Carolina and South Carolina. United States Geological Survey Professional Paper 1462: Washington, D. C., United States Government Printing Office.

Gehling, J. G., 1991, The case for Ediacaran fossil roots to the metazoan tree: Memoirs of the Geological Society of India, v. 20, p. 181-223.

Geyer, G. and Landing, E., 2001, Middle Cambrian of Avalonian Massachusetts: Stratigraphy and correlation of the Braintree trilobites: Journal of Paleontology, v. 75, p. 116-135.

Gibson, G. G., 1984, Ediacaran fossils from Stanly County, North Carolina; new evidence of the age of the Carolina Terrane terrane: Geological Society of America Abstracts with Program, v. 16, p. 18.

Gibson, G. G., 1989, Trace fossils from late Precambrian Carolina Terrane, south-central North Carolina: Journal of Paleontology, v. 63, p. 1-10.

Gibson, G. G. and Huntsman, J. R., 1988, Re-examination of the Gold Hill shear zone, Cabarrus and Stanly County area, south-central North Carolina: Southeastern Geology, v. 29, p. 51-64.

Gibson, G. G. and Teeter, S. A., 1984, A Stratigrapher's View of the Carolina Terrane, southcentral North Carolina: Carolina Geological Society 1984 Field Trip Guidebook, 12 p.

Gibson, G. G. and Teeter, S. A., 1988, Variations in the geometry of the petaloid Ediacarian body fossils from the Carolina Terrane, south-central North Carolina: Geological Society of America Abstracts with Program, v. 20, p. 267.

Gibson, G. G. and Teeter, S. A., 2000, Ediacaran fossils from the Carolina terrane, Stanly County, south-central North Carolina revisited: Geological Society of America Abstracts with Program, v. 32, p. 20.

Gibson, G. G. and Teeter, S. A., 2001, Additional Ediacaran fossils from the Late Precambrian Carolina Terrane, South-Central North Carolina: Southeastern Geology, v. 40, p. 231-240.

Gibson, G. G., Teeter, S. A. and Fedonkin, M. A., 1984, Ediacarian fossils from the Carolina Terrane, Stanly County, North Carolina: Geology, v. 12, p. 387-390.

Glaessner, M. F. and Wade, M., 1966, Late Precambrian fossils from Ediacara, South Australia: Palaeontology, v. 9, p. 599-628.

Goldsmith, R., Milton, D. J. and Horton, J. W., 1989, Geology of the Charlotte 1°x2° quadrangle *in* Gair, J. E., ed., Mineral resources of the Charlotte 1°x2° quadrangle, North Carolina and South Carolina. United States Geological Survey Professional Paper 1462: Washington, D. C., United States Government Printing Office, v. p. 7-15.

Gürich, G. 1933. Die Kuibis-Fossilien der Nama Formation von Sudwestafrika: Paläontogische Zeitschrift, v. 15, p. 137-154.

Grazhdankin, D. V. and Ivantsov, A. Yu., 1996, Reconstructions of biotopes of ancient Metazoa of the Late Vendian White Sea biota: Paleontological Journal, v. 30, p. 674-678.

Hibbard, J., 2000, Docking Carolina; mid-Paleozoic accretion in the Southern Appalachians: Geology, v. 28, p. 127-130.

Ivantsov, A. Yu. and Grazhdankin, D. V., 1997, A new representative of the Petalonamae from the Upper Vendian of the Arkhangelsk Region: Paleontological Journal, v. 31, p. 1-16.

Jenkins, R. J. F., 1992, Functional and ecological aspects of Ediacaran assemblages *in* J. H. Lipps and P. W. Signor, eds., Origin and Early Evolution of the Metazoa: New York, Plenum Press, v. p. 131-176.

Keller, B. M. and Fedonkin, M. A., 1976, Novye nakhodki okamenolostei v valdaiskoi serii dokembriya po r. Syuz'me: Izvestiya Akademiya Nauk SSSR, serii Geologicheskaya, v. 1976, n. 6, p. 86-102.

Keller, B. M., Menner, V. V., Stepanov, V. A. and Chumakov, N. M., 1974, Novye nakhodki Metazoa v vendomii Russkoi platformy: Izvestiya Akademiya Nauk SSSR, serii Geologicheskaya, v. 1974, n. 12, p. 130-134.

Keppie, J. D., Nance, R. D., Murphy, J. B. and Dostal, J., 2001, Eastern Pacific analogue for Avalonian and correlative peri-Gondwanan terranes: Geological Society of America Abstracts with Program, v. 33, p. 208.

Milton, L. W., 1985, Chimney fossils—surprising fossil discoveries in the Carolina Terrane resemble specimens found in Africa, Russia and Australia: Earth Science, v. 38, p. 24-27.

McMenamin, M. A. S., 1982, A case for two Late Proterozoic-earliest Cambrian faunal province loci: Geology, v. 10, p. 290-292.

McMenamin, M. A. S., 1988a, Palaeocological feedback

of segments and in their number, in the absence of a smooth zone (*zona levis*) and in the constitution of the medial zone, and also in the course of the commisurae and of the petaloid canals in examples from the Valdai Series. It is difficult to account for these differences between *Pteridinium* from the Valdai Series and from the Nama Group solely on the basis of taphonomic or preservational differences. [translation by M. McMenamin]

Distribution and age. McManus Formation, Albemarle Group, Carolina Terrane, Stanly County, North Carolina; Rawnsley Quartzite, Pound Supergroup, Ediacara, South Australia; Valdai Series, White Sea and Podolia, Russia; all Late Proterozoic.

Kingdom Animalia
Phylum Arthropoda
Class Trilobita
Order Ptychopariida
Suborder Ptychopariina
Superfamily Solenopleuracea
Family uncertain
Genus *Braintreella* Wheeler, 1942

***Braintreella* sp.**

Synonymy:

?Agraulos sp. Samson and others, 1990.

Diagnosis. A solenopleurid trilobite with tapering, smooth-surfaced, subtruncate glabella and distinctive preglabellar field and anterior border. The anterior border consists in part of a straight line perpendicular to (and centered on) the long axis of the glabella. The straight section is terminated on both sides by an inflection point, followed by curving of the anterior border toward the posterior of the animal. The length of the straight section of the anterior border approximately equals the length (sag.) of the glabella.

Remarks. This trilobite differs at the species level from *Braintreella rogersi* (Walcott, 1884) in the length of the straight section of its anterior border. In *Braintreella* sp. from South Carolina, the length of the straight section of the anterior border approximately equals the length (sag.) of the glabella, whereas in *Braintreella rogersi*, the length of the straight section of the anterior border exceeds the length (sag.) of the glabella. Otherwise the trilobites from South Carolina and Massachusetts are quite similar.

Braintreella sp. probably represents an undescribed species, but as it is currently represented by only a single specimen (Samson and others, 1990, their Fig. 6f), description of the new species must await discovery of additional material.

Distribution and age. "Asbill Pond formation" (informal name) of South Carolina, Carolina Terrane, Middle Cambrian, *Ptychagnostus atavus* Interval-zone of Samson and others (1990).

ACKNOWLEDGMENTS

We thank the Geology/Paleontology Division of the North Carolina State Museum of Natural Sciences for assistance with various aspects of this research. Specimens with NCSM numbers are deposited in the North Carolina State Museum of Natural Sciences; PIN numbers refer to the Russian Paleontological Institute. Henry Rust prepared the photograph for Figs. 2 and 5B and R. Chris Tacker prepared the photographs for Fig. 5A. Thanks to G. G. Gibson and S. Teeter for review comments, and to G. G. Gibson for permission to photograph specimens shown in figures 3 and 4.

REFERENCES CITED

Bream, B. R., Hatcher, R. D., Miller, C. F., Carrigan, C. W. and Fullagar, P. D., 2001, Provenance and geochemistry of late Proterozoic Southern Appalachian crystalline core paragneisses, NC-SC-GA-TN: Geological Society of America Abstracts with Program, v. 33, p. 29.

Cloud, P., Wright, J. and Glover, L., 1976, Traces of animal life from 620-million-year-old rocks in North Carolina: American Scientist, v. 64, p. 396-406.

Conley, J. F., 1959, Impressions resembling worm burrows in rock of the Carolina volcanic-sedimentary group, Stanly County, North Carolina: Southeastern Geology, v. 1, p. 133-137.

Conley, J. F., 1962, Geology of the Albemarle Quadrangle, North Carolina: North Carolina Department of Conservation and Development Division of Mineral Resources Bulletin, v. 75, p. 1-26.

Dockal, J. A. and Huntsman, J. R., 1990, Application of turbidite sedimentology to determination of thrust fault displacement in the Carolina Terrane: Journal of Structural Geology, v. 12, p. 285-296.

and the Vendian-Cambrian transition: Trends in Ecology and Evolution, v. 3, p. 205-208.

McMenamin, M. A. S., 1988b, The Dawn of Animal Life: Episodes, v. 11, p. 229-230.

McMenamin, M. A. S., 2001a, Evolution of the Noösphere. Teihard Studies Number 42: New York, American Teilhard Association, 30 p.

McMenamin, M. A. S., 2001b, The Garden of Ediacara and the appearance of complex life *in* S. Guerzoni, S. Harding, T. Lenton and F. Ricci Lucchi, eds. Earth System Science: Siena, Italy, University of Siena and Consiglio Nazionale delle Ricerche, v. p. 61-68.

McMenamin, M. A. S. and McMenamin, D. L. S., 1990, The Emergence of Animals—The Cambrian Breakthrough: New York, Columbia University Press, 217 p.

Meissner, R., Sadowiak, P. and Thomas, S. A., 1994, East Avalonia, the third partner in the Caledonian collisions: Evidence from deep seismic reflection data: Geologische Rundschau, v. 83, p. 186-196.

Pflug, H. D., 1970, Zur fauna der Nama-Schichten in Sudwest-Afrika. I. Pteridinia, bau und systematische zugehorigkeit: Palaeontographica Abt., v. A134, p. 226-262.

Richter, R., 1955, Die ältesten Fossilien Süd-Afrikas: Senckenbergiana Lethaea, v. 36, p. 243-289.

Runnegar, B., 1992, Proterozoic fossils of soft-bodied metazoans (Ediacara faunas) *in* J. W. Schopf and C. Klein, eds., The Proterozoic Biosphere: Cambridge, Cambridge University Press, v. p. 999-1007.

Runnegar, B. and Fedonkin, M. A., 1992, Proterozoic metazoan body fossils *in* J. W. Schopf and C. Klein, eds., The Proterozoic Biosphere: Cambridge, Cambridge University Press, v. p. 369-388.

Samson, S. D., Hibbard, J. P., van Staal, C. R. and Cawood, P. A., 1995, Is the Carolina Terrane part of Avalon?: Geolocial Association of Canada Special Paper, v. 41, p. 253-264.

Samson, S., Palmer, A. R., Robison, R. A. and Secor, D. T., 1990, Biogeographical significance of Cambrian trilobites from the Carolina Terrane: Geological Society of America Bulletin, v. 102, p. 1459-1470.

Secor, D. T., Samson, S. L., Snoke, A. W. and Palmer, A. R., 1983, Confirmation of the Carolina Terrane as an exotic terrane: Science, v. 221, p. 649-651.

Seilacher, A., 1989, Vendozoa-Organismic construction in the Proterozoic biosphere: Lethaia, v. 22, p. 229-239.

Sokolov, B. S. 1976. Metazoa dokembriya i vendo-kembriiskii rubezh: Paleontologicheskii Zhurnal, v. 1, p. 13-18.

Sokolov, B. S. and Fedonkin, M. A., 1984, The Vendian as the terminal system of the Precambrian: Episodes, v. 7, p. 12-19.

St. Jean, J., 1973, A new Cambrian trilobite from the Piedmont of North Carolina: American Journal of Science, v. 273A, p. 196-216.

Sundelius, H. W. and Stromquist, A. A., 1978, Interpretive geologic map of the bedrock, Mount Pleasant Quadrangle, Cabarrus and Stanly Counties, North Carolina: United States Geological Survey Miscellaneous Investigations Series Map I-1082.

Teeter, S. A., 1983, New trilobite (?) locality from the Carolina Terrane, Stanly County, North Carolina: Journal of the Elisha Mitchell Scientific Society, v. 99, p. 151.

Teeter, S. A., 1984, *Pteridinium* from the Carolina Terrane, Stanly County, North Carolina: Geological Society of America Abstracts with Program, v. 16, p. 66.

Teeter, S. A., and Bryden, R. R., 1984, Reappraisal of fossil evidence from the Terrane, Stanly County, North Carolina: Journal of the Elisha Mitchell Scientific Society, v. 100, p. 149-150.

Torsvik, T. H., Smethurst, R., van der Voo, R., Trench, A., Abrahamsen, N. and Halvorsen, E., 1992, Baltica: A synopsis of Vendian-Permian paleomagnetic data and their paleotectonic implications: Earth Science Reviews, v. 33, p. 133-152.

Waggoner, B., 1999, Biogeographic analyses of the Ediacora biota: a conflict with paleotectonic reconstructions: Paleobiology, v. 25, p. 440-458.

Walcott, C. D., 1884, On the Cambrian faunas of North America: United States Geological Survey Bulletin, v. 10, p. 289-355.

Weyl, H., 1956, Symmetry *in* J. R. Newman, ed., The world of mathematics: New York, Simon & Schuster, v. p. 671-724.

Wheeler, R. R., 1942, New Mid-Cambrian ptychoparid: American Journal of Science, v. 240, p. 567-570.

Wright, J. E. and Seiders, V. M., 1980, Age of zircon from volcanic rocks of the central North Carolina Piedmont and tectonic implications for the Carolina volcanic Terrane: Geological Society of American Bulletin, v. 91, p. 287-294.